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Proceedings of the Special Session on Salmonid Aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA

R. H. Cook and W. Pennell, Editors

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PROCEEDINGS OF THE SPECIAL SESSION ON SALMONID AQUACULTURE, WORLD AQUACULTURE SOCIETY, FEBRUARY 16, 1989, LOS ANGELES, USA

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FOREWORD

The rate of growth of coldwater aquaculture development in the more temperate zones of the world has been steady but relatively unspectacular for many decades. It is really a phenomenon of the 80's that the production and marketing of cultured salmon has forced its way into becoming a global commodity of major proportions. One senses that the salmon aquaculture industry has become an economic front runner almost within a single decade. As the 80's proved and refined the capabilities of salmon production on a massive scale, the 90's will be the decade of product quality, marketing and environmental issues that will, and may have already, limited the apparent unbridled growth.

In the planning for the World Aquaculture Society meetings in Los Angeles in 1989, the Program Committee decided that Special Sessions should focus on several of the major aquaculture species groups where progress in terms of science and technology, as well as commercial development, had been substantial. Accordingly, a Special Session was identified for the Aquaculture '89 Conference on the topic of Salmonid Aquaculture.

The growth of salmon aquaculture has been noteworthy in several areas of the world. It was decided, therefore, that speakers would be invited to provide status reports on salmonid aquaculture from their respective regions. The papers in this collection provide a good perspective on the development and status of salmon aquaculture in a number of the leading areas including Norway, Scotland, Chile, the east and west coasts of North America and Tasmania. A comprehensive report on the status of salmon farming in Japan was presented at the WAS Aquaculture '89 conference by Noritada Endon; unfortunately, it was not available for this collection. In addition, it was recognized that salmon aquaculture is developing rapidly in New Zealand; however, the speaker was unable to attend the Special Session. Notwithstanding these omissions, the reader has an opportunity to obtain important insight into the development of salmon aquaculture within a broad geographical range.

Trout culture is an important component within the context of salmonid aquaculture. The freshwater aspects of salmonid culture have developed over many decades and, indeed, commercial trout operations are well established in most countries where salmon culture is now being practised. In fact, trout culture has a much broader range of application. One of the world's major trout growing areas is in Idaho, USA, and Ernest L. Brannon provided the Special Session an excellent overview of this thriving industry. It is regrettable his paper was not available for this collection.

The Special Session on Salmonid Aquaculture did, however, address a number of the important technological issues that impinge on the successful development of the salmon industry. The need for fish health protection of salmonid resources has been predominant in many producing nations; a review of the Canadian experience is presented. Broodstock development is also increasingly important as salmon production increases and there becomes a requirement to preserve those strains which show improved performance under culture conditions. One paper on this topic describes the initiatives ongoing in Norway; another discusses the approaches being pursued in fish genetics research.

From a salmon aquaculturist's perspective, feed types, costs and related growth performance are key operational factors. Excellent overviews were provided on the availability and sources of fish meal, feed production and on the essential elements of salmonid nutrition. Papers in this collection also address the research developments in smolt production and in the use of biologically active proteins in enhancing the growth of salmonids.

Although only briefly, the question of environmental impacts of salmon aquaculture was considered at the Special Session. A paper was presented by Harold Rosenthal which documented the serious degradation of a marine embayment resulting from excessive salmon production. This paper was not available for this collection.

The accelerated production rates of cultured salmon from Europe, North America, South America, Australia, New Zealand and Japan are rapidly altering the international market for salmon. An assessment in this collection has been provided on a study of the American and Japanese markets for farmed salmon; it also provided useful insight in the specific product characteristics expected by the consumer, in particular the retail and restaurant sectors. Geographic differences in product preferences are also considered. The issues of specialized client product requirements, product quality and the dynamics of the global marketplace, along with a plethora of environmental issues, will dominate the salmonid aquaculture agenda of the 90's.

The papers that follow provide a useful perspective on the global development of salmonid aquaculture and on a number of issues of importance to this industry. We believe this collection serves as a suitable synopsis of the Special Session on Salmonid Aquaculture at WAS Aquaculture '89 Conference.

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THE POTENTIAL AND CONSTRAINTS OF THE NORWEGIAN SALMON AQUACULTURE PRODUCTION

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Hansen. T. 1991. The potential and constraints of the Norwegian salmon aquaculture production, p. 1-8. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

THE ORIGIN OF SALMONID FARMING IN NORWAY

The development and success of the Danish rainbow trout culture was followed with great interest in Norway in the early 1950's. However, Norway, with its low winter temperatures, did not have the same natural advantages as Denmark for the rearing of rainbow trout in fresh water. Consequently, one had to look for alternative methods of production and, for obvious reasons, the culture of rainbow trout in seawater was tested. Within a short time, the Vik brothers, at Sykkylven, demonstrated the commercial feasibility of the seawater rearing of rainbow trout.

In the mid-1960's, Norwegian fish farmers turned their interest towards the Atlantic salmon. As salmon commands a much higher price and has marketing advantages, this species seemed to present greater development potential. However, one had first to solve the technical problems involved with seawater rearing. Different approaches such as the MOWI sea enclosure (Milne 1972), the beach enclosure of Mr. Erling Osland (Edwards 1978) and the "Grøntvedt cage" had two major advantages: an easily managed size and a very low price. The "Grøntvedt cage" was later refined into the cage systems which are used today for the production of almost all Norwegian salmon.

It soon became apparent that the salmon was easily reared in sea cages. It also became obvious that Norway's long coastline with its many protected fjords, inlets and bays, in combination with a stable seawater temperature, provided excellent natural conditions for the growth of the salmon industry. Moreover, Norway had a supply of suitable foodstuffs from its fishing industry which were capable of supporting a large salmonid farming industry.

THE INDUSTRY AND ITS STRUCTURE

The Norwegian Fish Farmers' Association (NFF) was founded in 1970 as a professional organization for the fish farmers. Its purpose was to assemble all Norwegian farmers of fish and other organisms in order to advance their economical, professional, social and cultural interests. In 1978, the Norwegian Fish Farmers' Association took the initiative to establish the Norwegian Fish Farmers' Sales Organization (FOS). The FOS has the sole right for the primary sale of all farmed fish and shellfish. It is therefore prohibited to manufacture, sell or export cultivated fish products if they have not been sold first hand through, or with the approval of, the FOS. By controlling the initial sale of farmed products, the FOS seeks to obtain fair, stable prices and safe terms of payment (decisions on minimum prices and approval of buyers). To manage the marketing activities, the industry has established a Marketing Council which serves as a liaison between the FOS and the buyers/exporters. The function of the Marketing Council is to promote the sale of cultivated fish through joint marketing measures. This is financed through a fee charged by the FOS on all first-hand sales of aquaculture products.

In addition, the FOS has distributed information through courses, the magazine INFOS, the nationwide data network MARINET and the AQUA-NOR exhibitions. FOS is also a strong supporter of the work to improve fish health. Consequently, FOS grants funds to the research program "Healthy Fish" through The Norwegian Fisheries Research Council (NFFR).

THE GOVERNMENTAL POLICY

As a result of the increasing interest in fish farming, a law was passed in 1973 which prohibited the establishment and further expansion of fish farms without an official licence. The same law placed the administration of the fish farming industry under the Ministry of Fisheries. In the period from 1973 to 1988, licensing of fish farms has been based on a maximum size restriction which varies between 5000 and 8000 m^3. This upper size limit has ensured that the benefits of the new industry have been more widely spread and have encouraged the establishment of a number of small units.

The primary objective of the policy on aquaculture is to promote the development of a profitable, viable and economically independent regional industry and to develop it to become one of the main forms of industry for the coastal communities. To meet this objective, the authorities assume certain costs and obligations. In the opinion of the government, however, these costs are well justified as this type of structure, in contrast to a more centralized industry, is of greater benefit to the Norwegian society as a whole.

The public authorities' contribution includes direct measures to stimulate the development of the industry, as well as to provide such services as research and development, advisory services, education, veterinary services, etc. As a further incentive for the development of the industry in outlying districts, the government guarantees loans through the Regional Development Fund.

At the same time, the authorities carry out regulating and control functions through various forms of legislation, including licensing arrangements and associated conditions, quality control, requirements for the control of disease, etc. These regulations restrict the freedom of the actual operators of the industry to a large degree. However, these measures have been introduced to ensure that society receives the maximum benefit from the industry, at the same time reducing, to the furthest extent possible, any injurious effects on the environment and conflicts between users. Until now, the functions and responsibilities of the authorities have not been adequately implemented. It will be necessary, therefore, to make adjustments in certain areas to strengthen the role played by the central authorities.

THE ISSUE OF LICENCES

The decision-making process involved with the issuance of each round of licences takes many steps and is extremely cumbersome and time consuming. The decision as to when, how many, and to which part of the country new licences are to be issued is made by the Ministry of Fisheries and, once made, is publicly announced. The applicants in each county are evaluated and assessed by the Chief of Fisheries at the Directorate of Fisheries who makes recommendations based on a framework provided under the Fish Breeding Act. Among other things, this legislation sets minimum requirements, taking into account the competence of the applicant. The Chief of Fisheries refers the applications to the local Fisheries Councils which, in turn, send their recommendations back to the Directorate of Fisheries. The applications are again sent to the local authorities. The application is then announced publicly and sent, in turn, to the Coastal Authorities to be evaluated under the Harbour Act, to the Counties Environmental Office to be evaluated under the Pollution Act and to the County Veterinary Office to be evaluated under the Disease Act. The extent of these administrative procedures bears no relation to the number of cases to be considered and the need for studies and investigations connected with the aquaculture industry. A fee has recently been placed on licence applications in order to obtain funds to pay for the costs of the public administration in this sector.

In the upcoming issuance of new licences, an effort will be made to make the procedure more rational and effective. Plans have also been made to improve the present legislation to ensure better compliance with (the intentions of) the Fish Breeding Act.

THE GROWTH OF THE SALMON INDUSTRY

Salmonid farming has been a fast growing industry. In 1973, 287 producers produced 171 tons of salmon and 1001 tons of rainbow trout (Table 1, 2). By 1988, the number of producers had increased to 747 and the total production of salmon and rainbow trout had increased to 80,000 and 7500 tons, respectively. This is close to eight times the total catch of wild Atlantic salmon in the world and more than 70% of the world's total production of farmed Atlantic salmon for 1988. The growth of the industry has been especially fast from 1985 onwards. The growth in the amount of processed salmon from 1985 to 1986, and from 1987 to 1988, was 58% and 68%, respectively.

In 1987, 90% of the salmon and 30% of the trout produced in Norway were exported. The export value of the salmon alone was $333 million US. The major markets for Norwegian salmon are given in Table 3.

So far, the farming of salmon and trout has been very profitable. In 1985, the smolt production sector showed a net return per person-year (i.e. total income available for wages, minus total costs including calculated depreciation and interest on equity capital) of $73,000 US, and the return on total assets averaged 30%. The comparable figures for the sector producing market size fish were $42,000

Table 1. The Norwegian salmonid production and value. Data from official statistics from the Directorate of Fisheries.

Year	Atlantic Salmon		Rainbow trout	
	Tonnes	$US('000)	Tonnes	$US('000)
1972	146		778	
1973	171		1001	2
1974	601	2	21726	2
1975	862	3	1655	3
1976	1431	6	2045	5
1977	2137	10	1795	5
1978	3540	16	2105	5
1979	4389	26	2988	9
1980	4312	29	3668	11
1981	8418	42	4624	12
1982	10695	57	4627	15
1983	17298	100	5405	18
1984	21881	130	3569	14
1985	28656	198	5104	22
1986	45494	242	4248	23
1987	47418	296	8787	30
1988	80000	523	7500	
1989	120000		6000	

Table 2. The number of Norwegian producers and rearing volumes. Data from official statistics from Directorate of Fisheries.

Year	Hatcheries	Smolt producers	Food fish producers	Rearing volume, m^3
1973	214	17	287	975,000
1974	227	208	321	1,126,000
1975	229	210	324	1,135,000
1976	235	220	346	1,238,000
1977	241	228	414	1,687,000
1978	245	236	448	1,881,000
1979	255	259	463	1,935,000
1980	280	284	468	1,960,000
1981	287	293	506	2,046,000
1982	287	294	581	2,210,000
1983	330	350	581	2,210,000
1984	339	366	665	3,380,000
1986	542	566	704	4,995,150
1987	633	659	747	5,464,150
1988	667	692	786	5,902,566

US and 18.5%. The industry had a total consumption of $615 million US including investments in 1988.

Table 3. The major markets for Norwegian salmon in 1987.

Country	Export (tonnes)
France	11,424
USA	8,424
Denmark	7,903
Germany	4,715
Sweden	2,052
Spain	1,993
Great Britain	1,642
Japan	1,553
Belgium	1,451
Switzerland	1,137

By the end of 1988, approximately 4500 people were directly employed in the production of salmonids. It has also been estimated that a similar number are employed in related support activities.

THE PROBLEMS

Despite the tremendous growth, the industry has faced, and is still facing, serious problems.

DISEASES

Diseases remain the most serious problem in the production of farmed fish; however, the extent of the outbreaks and the losses due to disease vary from year to year. The economic significance of infectious diseases is very difficult to estimate and no satisfactory investigative methods exist that can document the losses. However, if one considers the two diseases, 'vibriosis' and 'cold-water vibriosis', it is clear that these diseases alone have caused mortalities and reduced production amounting to more than $100 million US during the last years. The identification and description of the causative agent, the bacteria *Vibrio salmonicida*, and the development of the vaccine, is the most important result, in economic terms, that aquaculture research has contributed to the fish farming industry.

The most important diseases in Norwegian salmonid farming are presented in Table 4. The IPN virus is by far the most common pathogen and it is highly probable that this virus is present in all Norwegian fish farms. Salmon losses due to the IPN virus are, however, negligible.

The mortalities due to the other diseases listed in the table seem to be moderate. Yersinosis has caused mortalities in some smolt farms in connection with the transfer and acclimation of smolts to seawater. Even mortalities caused by the diseases furunculosis and BKD are moderate.

However, the danger of infecting wild populations and other fish farms has led the veterinary authorities to treat these diseases very restrictively. Any infected farm has been directed to carry out a sanitary slaughtering process; all fish in infected smolt farms must also be killed and destroyed. The fish farmer, therefore, not only incurs losses due to mortalities, but also because the stocks of fish have to be slaughtered before normal market size is achieved. Moreover, fish with drug residues cannot be used for any purpose and must be destroyed. Much concern has also been raised regarding the increased use of drugs and chemicals. These are spread to the environment and may have long-term effects. We, as yet, know too little about the environmental consequences of these measures.

A GENERAL LACK OF KNOWLEDGE AND EXPERTISE

The Norwegian salmon industry has, from the beginning, experienced a general lack of skilled technicians, farm managers and academically educated personnel. From the start, this was a natural result of the lack of knowledge that existed in this new industry. The expansion of the industry has, however, not been followed up by a necessary improvement and expansion of aquaculture education. Moreover, opportunities to pursue education in aquaculture-related subjects have arisen without any overall planning and coordination. Aquaculture is a knowledge-intensive industry. An increased level of knowledge will be required amongst those already in the industry, and in its organization and administration. Greater efforts in the

Table 4. The most important diseases in the Norwegian salmon industry.

Disease	Vaccine	Treatment
Vibriosis	Yes	Antibiotics
Cold-water vibriosis	Yes	Antibiotics
Bacterial kidney disease	No	No
Furunculosis	No	Antibiotics
Yersinosis	Yes	Antibiotics
Infectious pancreatic necrosis		No

educational sector will be necessary in the years to come.

SHORTAGE OF SALMON SMOLTS

The fish mortality rate in Norwegian smolt production has been surprisingly high. Hansen and Holm (1987) reported that egg to smolt mortalities varied between 56 and 76% in the period from 1979-85. The authors attributed these problems to a general lack of skilled personnel and the introduction of unsuitable technical equipment. As a consequence of the shortage of salmon smolts, the prices increased to between $2 and $5 US, depending on district. This made smolt production highly profitable despite the high mortalities. However, the high smolt prices increased the cost of producing market-size salmon considerably. The shortage of smolts was solved by removing the governmental restrictions on smolt production. This resulted in an increase in the number of production units. The new law was formally established in 1985; however, the restrictions were removed from 1983. The removal of these governmental restrictions led to a remarkable increase in smolt production. In 1988, Norway, for the first time, experienced an overproduction and the prices dropped to between $1 and $1.5 US for a top quality smolt.

USER CONFLICTS IN THE COASTAL ZONE

An aquaculture facility requires a certain area of sea and large quantities of clean water, and simultaneously affects the surrounding environment. On the other hand, aquaculture is extremely sensitive towards adverse influences from the surrounding environment. LENKA is a project involving cooperation between the Ministry of Fisheries and the Ministry of Environment. The results of this project are intended to help the municipalities in their planning of the coastal zone and watercourses. Part of the project is concerned with developing professional advice which can be used in the planning and siting of aquaculture facilities. In addition, a description will be prepared of sea areas and watercourses in relation to their suitability and capacity for aquaculture, based on charting of environmental conditions, trade, industry, protection and outdoor interests, etc.

THE ENVIRONMENTAL EFFECTS

In recent years, much attention has been directed to the environmental effects caused by marine fish farms. Most of the attention has been placed on the increased use of drugs and chemicals, releases of nutrients to receiving waters, the risk of infecting wild stocks with diseases, and the effect of the fish-farm escapees on natural stocks.

In a large investigation on the environmental effects of marine fish farms, Aure et al. (1988) concluded that the environmental impact of fish farming in the sea is limited to the immediate surroundings of the farms. The environmental impact is modest compared to its theoretical release of nutrients and organic compounds. This may be because much of this is bound to larger particles which may be consumed immediately or settle to the bottom directly under the fish farm.

The knowledge of how the increasing number of farmed fish affects the natural stocks is insufficient. Many managers and fishermen are concerned about the preservation of wild stocks. To reduce this risk, protective measures have been adopted, such as establishing areas free from fish farms around the most important salmon rivers. Work to reduce the numbers of fish-farm escapees has also been given importance.

THE RESEARCH

The first investigation that was defined as "aquaculture research" was started in Norway in the late 1960's. This was performed by the Institute of Nutrition and Institute of Marine Research under the Fisheries Directorate and by the University of Agriculture.

In the early 1970's, two research stations were built. Matre Aquaculture Station was founded under the Fisheries Directorate, Institute of Marine Research, to perform research on fish breeding, under the Ministry of Fisheries. The Research Station at Sunndalsøra was founded to perform the same research under the Ministry of Agriculture. During the 1970's, the research was very uncoordinated and much of the same research was done at both research stations.

The growth of the aquaculture industry has led to a tremendous increase in the efforts spent on aquaculture research. To illustrate this rapid growth, the person-years of effort spent on aquaculture research at the Institute of Marine Research are presented in Table 5. Starting in 1970, aquaculture research has grown from modest beginnings to making up 40% of the Institute's research activities in 1987.

As the importance of the aquaculture industry increased, more and more aquaculture research institutes appeared. In recent years, it has been of increasing importance that the coordination and distribution of research assignments be improved to ensure that public resources are more effectively utilized. Cooperation has been established between the different research councils, with the main responsibility being that of the Norwegian Council for Fishery Research.

In 1984, the Aquaculture Committee was appointed by the Ministry of Fisheries. In 1987, it delivered the "National Plan of Action for the Aquaculture Research." This national plan of action defines eight main program areas:

1. Production plant and operating conditions
2. Feed/feeding resources
3. Health/environment/disease
4. Breeding/genetics
5. New species
6. Sea ranching
7. Finances, product, distribution, market and society
8. Development of expertise.

The Committee also recommends that three of these areas - health/ environment/disease, new species and development of expertise - are established as national research programs.

Aquaculture will continue to be one of the government's high priority areas for research. The main effort within research and education in the field of aquaculture must be directed at the continued development of a national, competitive industry in the widest meaning of the term, adapted to the advantages and possibilities that Norway has to offer.

With increased production of salmon, both in Norway and abroad, the price level will be more important in the future than it has been up to now. In addition to meeting its regular deliveries and producing high quality products, the cost of cultured Norwegian salmon will become increasingly significant. Within the field of product development, and in private and public research and development (R&D) work, a systematic effort is being made to make the Norwegian fish farming industry more cost effective.

It is assumed that the research will be financed jointly by the public authorities and the industry. The state has a special responsibility for basic research, for R&D concerning the long-term development of the industry, and for the R&D necessary for management purposes. The Aquaculture Committee has, therefore, proposed that the government's involvement in aquaculture research should be increased from $20 million US in 1987 to $46 million US per year, and that investments in equipment and installations should be in addition to this figure. On the other hand, the industry itself is expected to bear the main responsibility for R&D directed at the short-term

Table 5. The development of research effort spent on aquaculture research at the Institute of Marine Research.

	1970	1980	1983	1984	1985	1986	1987
Total	139	228	248	257	273	277	282
Aquaculture	4	38	72	83	97	106	114
% aquaculture	3	17	29	32	35	38	40

needs of the industry. It is also reasonable that the industry should contribute to R&D directed at the long-term development of the industry.

In 1983, the aquaculture organizations took the initiative to start the research program "Healthy Fish" with the purpose of solving the problem of the cold-water vibriosis. This research program has been continued and expanded. Today the program is a research program on fish diseases with the purpose of coordinating and improving cooperation between the various institutions. The research funds in this program come from the Fish Sales Organization (FOS), Norwegian Fisheries Council (NFF), Norwegian Fisheries Research Council (NFFR) and the Norwegian Agriculture Research Council (NLVF). The program is coordinated by the Norwegian Fisheries Research Council. The Ministry of Fisheries and the Ministry of Agriculture are also interested and intend to have their own representation in the program. This improves the communication between government and the industry. The program has as its new objective to bring together both private and public interests to reduce fish mortalities in the industry.

REFERENCES

Aure, J., A. S. Ervik, P. J. Johannesen, and T. Ordemann. 1988. The environmental effects of sea water fish farms. Fisken Hav. 1988: I-XIV + 1-94, ISSN 0071-5638.

Edwards, D. J. 1978. Salmon and trout farming in Norway. Fishing News Books Ltd., Farnham, Surrey, England, 195 p.

Hansen, T. J., and J. C. Holm. 1987. Norwegian salmonid smolt production: expansion versus optimization. Int. Aquacult. Symp., Nov. 23-25, 1987, Instanbul, Turkey.

Milne, P. H. 1972. Fish and shellfish farming in coastal waters. Fishing News Books Ltd., Farnham, Surrey, England, 208 p.

THE DEVELOPMENT OF ATLANTIC SALMON FARMING IN SCOTLAND

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ABSTRACT

Munro, A. L. S. 1991. The development of Atlantic salmon farming in Scotland, p. 9-20. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

The growth of the Scottish salmon farming industry from its inception to its current size of 18,000 tonnes in 1988 is traced and annual estimates to 1991 presented. Current methods and scale of operation, analyses of operator size, fish health, social and economic benefits, current environmental issues, organization of associations, product quality control, markets and marketing are discussed.

RÉSUMÉ

Munro, A. L. S. 1991. The development of Atlantic salmon farming in Scotland, p. 9-20. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

On suit ici l'évolution de l'industrie de la pisciculture du saumon en Écosse, depuis ses débuts jusqu'en 1988, année où sa production atteignait 18 000 tonnes. On présente également des estimations annuelles de sa production jusqu'en 1991 et on traite de ses méthodes actuelles, de l'envergure de ses activités, de la taille des exploitations, de la santé du poisson, de ses avantages économiques et sociaux, des questions environnementales d'actualité, de l'organisation des associations, du contrôle de la qualité des produits, des marchés et de la commercialisation.

INTRODUCTION

Salmon farming in Scotland started in the late 1960's and developed at a slow pace throughout the 1970's as a small number of commercial companies learned how best to manage the 3- to 4-yr life cycle of this fish under the prevailing conditions. In the 1980's, growth has been so rapid that salmon farming is now called an industry. This paper is concerned with the period of rapid growth of the industry, and considers technical, economic and marketing achievements and some of the problems arising from growth.

PRODUCTION

Whereas a small number of farm sites (16) produced about 600 t of salmon in 1979, in 1988, 10 yr later, about 18,000 t were produced in 258 sites, and it is estimated that in 1989 over 30,000 t will be produced (Anon. 1979-1989; Munro and Waddell 1987). Most of the figures and tables produced in this paper are derived from the Department of Agriculture and Fisheries for Scotland's annual survey of fish farming activity produced in the author's laboratory over the last 10 yr. Returns of 100% are regularly received. Figures 1 and 2 show respectively the tonnages produced each year over this period and the numbers of smolts transferred to seawater. The value of the ex-farm product was approximately £80 million in 1988. Figure 3 shows the annual growth in numbers of fresh and seawater sites over the period from 1969. Sites are widely distributed on the west coast of the mainland of Scotland and on most islands of the western and northern coasts. Virtually no sea farming takes place on the east coast facing the North Sea, owing to its exposed nature. All the farming areas are unpolluted and water temperatures range from 5-15°C, ideal for salmon farming.

SEA GROWERS

In 1988, some 97% of production was from floating net cages and the rest from pump ashore farms. Cage design has undergone considerable development in recent years and has contributed greatly to the dramatic growth of salmon farming. The principal development has been larger cages, the size having increased from 200-500 m^3 to 1000-2000 m^3 and the older

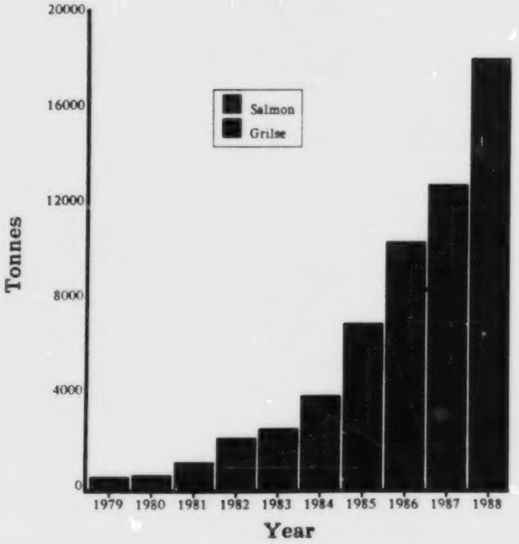

Fig. 1. Annual production of farmed Atlantic salmon in Scotland, 1979-88.

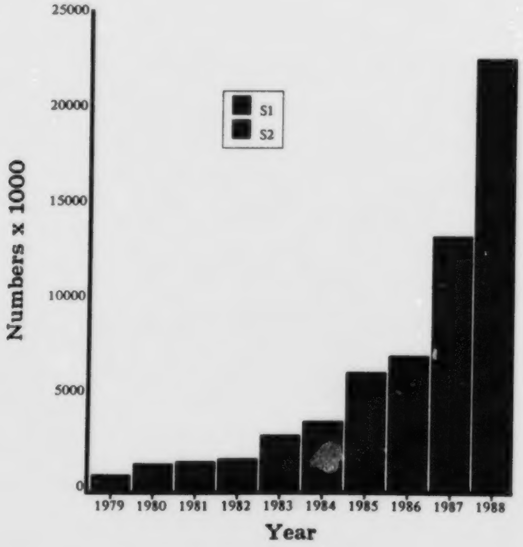

Fig. 2. Annual production of farmed smolts in Scotland 1979-88.

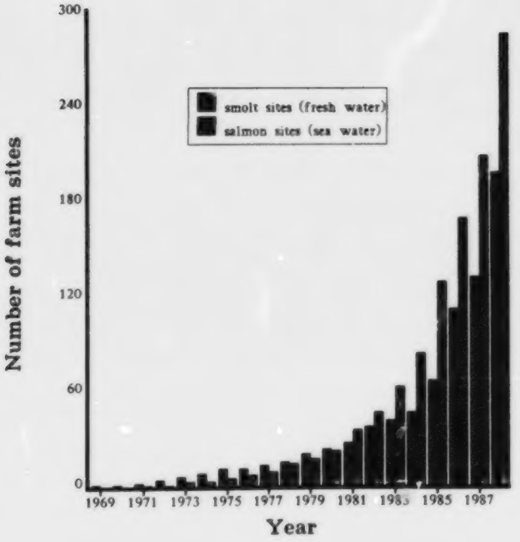

Fig. 3. Number of Atlantic salmon farm sites in operation in Scotland 1969-88.

wooden frames having been replaced by a variety of other materials including steel, plastic and rubber. This has allowed use of more exposed environments, of which Scotland has many. Larger cages are better for fish growth although they can pose problems for management because of their size.

The significant increase in production at the present time is largely due to expansion of cage numbers on existing sites. Relatively sheltered new sites with adjacent, easy to service shore facilities are becoming difficult to obtain, partly because of genuine scarcity and partly because of other competing pressures. However, assuming factors such as market forces or disease do not restrict production, it is probable that existing sites will be capable of producing 50-60,000 t by the early 1990's. Expansion beyond this level will probably depend upon exploitation of new, more exposed sites using robust cage designs, and already there is evidence that developments are moving in this direction.

The technology associated with managing large sites stocked with big cages is changing rapidly at present. Some individual sites are already producing 500 t annually (Table 1) and more are expected to do so in 1989. As a result, the equipment to handle the greater volumes of feed and fish are becoming more complex and expensive. In particular, fish pumps and graders and automated computer controlled feed systems with bulk storage reservoirs are receiving a lot of attention. The next area of development may well be non-intrusive devices to observe, size and count fish. Many sites with fish have yet to produce their first harvest, and some sites are still being built but have already been recorded in our list of registered sites.

Scottish farmers still have to contend with about 30% (by number) of fish maturing early, i.e. grilsing (Table 2, column 18). By tonnage, grilse represent about 20% of production. Research in the author's laboratory (Johnstone 1989) to overcome this problem has shown that production of sterile fish, by pressure shocking all female stocks within minutes of egg fertilization to produce triploids, has great potential. In each of three year-classes, approximately one million fish have been treated in this way and are now growing in commercial conditions. Rates of triploidy in these treated fish were almost 100% and survival within 5-10% of controls at eyeing stage. Subsequently, growth and survival rates have been similar to those of untreated fish maturing as salmon, i.e. the slower growing fraction.

Table 2 (columns 6 and 11) also shows that the mean weight of grilse and pre-salmon harvested in the period 12-19 mo after entry to seawater, and mean weight of salmon harvested 20-24 mo later, were relatively constant. They do not indicate strong market forces dictating changing preferences for size. The table illustrates how two year-classes contribute to an annual estimate of production based on the calendar year, e.g. the 1984 year-class of smolts produced 4350 t of salmon (column 10) in 1986 and the 1985 year-class of smolts produced 5988 tonnes of grilse and pre-salmon (column 5) in 1986, making the gross tonnage of 10,333 t (column 19) recorded for 1986.

Table 3 shows that tank systems operate at higher densities compared with cages, possibly because of economic necessity, but it also lends support to the operators' contention that disease at such densities is manageable.

Table 1. Grouping of sea farm sites by the scale of their production in 1988.

Production (tonnes)	0	<10	10-25	26-50	51-100	101-200	201-300	301-400	401-500	>500	Totals	
											Sites	Tonnes
No. of sites	97	14	46	37	29	37	13	6	3	2	284	17,951
% share of production	-	0.32	4.39	7.47	12.96	29.26	17.72	12.28	7.45	8.14		

Table 2. Atlantic salmon - production record and estimates of future production.

Year	No of smolts to sea ('000)	Year of harv	No of grilse/ salmon ('000)	Wt (t)	Mean fish wt (kg)	% of fish rec'd	Year of harv	No of salmon ('000)	Wt (t)	Mean fish wt (kg)	% of fish rec'd	% total rec'd	Total harv (t)	No of surv's to prod 1 t	Total no to prod 1 t	Grilse no ('000)	% grilse	Annual prod (t)	
1984	3,628	1985	1,970	4,262	2.163	54.3	1986	1,168	4,350	3.723	32.2	86.5	8,612	364	421	1,084	34.5	1985	6,921
1985	5,586	1986	2,409	5,988	2.486	43.1	1987	1,522	5,521	3.627	27.3	70.4	11,508	342	485	1,090	27.7	1986	10,333
1986	6,774	1987	3,285	7,200	2.193	48.5	1988	1,750	6,086	3.480	25.8	74.3	13,286	379	510	1,526	30.3	1987	12,721
1987	13,106	1988	5,167	11,866	2.300	39.4	1989	3,408	11,928	3.500	26	65.4	23,794					1988	17,951
1988	20,921	1989	8,368	19,087	2.281	40	1990	5,440	19,040	3.500	26	66.0	38,127					1989	31,015
1989	26,770	1990	10,708	24,425	2.281	40	1991	6,960	24,360	3.500	26	66.0	48,785					1990	43,465
1990	31,159	1991	12,465	28,433	2.281	40	1992	8,101	28,354	3.500	26	66.0	56,787					1991	52.793

Fish in this box are based on estimates of % fish recovered and mean fish weight

Table 3. Seawater tank and cage capacity related to fish production.

System	No of sites compared	Capacity (m^3)	Production (tonnes)	Salmon produced (kg/m^3)
Tanks	6	11,152	263	23.6
Cages	244	4,546,878	30,265	6.7

SMOLTS

Parallel with sea fish production, smolt production has also had to achieve a rapid rate of growth from home-grown sources because imports of live smolts have never been allowed under UK disease regulations. The scale of production at sites varies greatly, but the projected rate of growth indicates that development at existing sites will continue in addition to any growth that may arise from production at new sites (Table 4). Probably the slow initial development of salmon farming was due in part to the difficulties of Atlantic salmon smolt production. Compared with most Pacific salmon and rainbow trout, the juvenile Atlantic salmon is the most demanding and biologically complex, but once it has been understood and commercial objectives have been set for hatchery managers, this complexity has not proved a permanent obstacle. Early hatching and good first feeding are critical in achieving 1-yr smolts. However, at ambient Scottish temperatures, it is not possible to achieve this with all fish, and large numbers of parr destined to be 2-yr smolts are culled. In 1988, 88% of smolts were 1-yr-old. However, large (>50 g) 2-yr smolts were preferred by some operators because they go to sea a month earlier and may be harvested in 12-18 mo at a good commercial size (>3 kg), thus achieving a more rapid return on capital.

Some 25% of salmon and grilse were produced in the northern isles of Orkney and Shetland where considerable sea site potential exists. However, as smolt production is severely restricted there due to lack of fresh water, large smolt shipments in well boats are made annually from the Scottish mainland.

A major Scottish development in smolt production has been the use of cages in freshwater lochs. Some 54% of the 1988 smolts were produced in this way compared with 40% in 1987. Parr are transferred at a range of sizes from 1-5 g in early to late summer and reared there until smolting. Ice is seldom a problem, and at several sites, temperatures are comparable to those in the sea. This has allowed a greatly expanded use of existing hatchery facilities (high in capital costs) combined with a freshwater cage site (low in capital costs). It is probable that in consequence Scottish smolt production costs are at least comparable to, if not significantly less than, those elsewhere. Table 4 shows that many sites are not in production. A small number are new but most are small cage sites which are in rotation and being rested.

Table 5 shows that yield per m^3 of rearing space is about six times as great in tank systems as in cages.

BROODSTOCK AND OVA

Significant numbers of Norwegian ova have been imported annually since the mid-1970's, with appropriate health certification. A very large proportion of Scottish farmed salmon are now of Norwegian genetic origin but, owing to increasing difficulties in achieving the appropriate health status for Norwegian broodstocks, these imports have now ceased. Some Scottish wild stocks have given growth and grilse ratios comparable to those of Norwegian stocks but, owing to their limited availability, imports were deemed necessary. Currently the industry is well geared to broodstock production, with approximately 82 million ova produced in the winter of 1988-89 from farmed sources.

Table 4. Grouping of smolt sites by the scale of their production.

Production (nos '000)*	0	<10	10-25	26-50	51-100	101-250	251-500	501-1000	>1000	Annual no of sites	Annual no of smolts
No of sites in 1988	66	6	18	23	28	30	13	12	1	197	22,499
Same sites estimates for 1989	61	5	12	27	20	35	21	13	3	197	28,740
Same sites estimates for 1990	55	1	12	26	30	30	24	15	4	197	33,621

*Includes 21 sites not in production during 1988.

Table 5. Tank and cage capacity related to smolt production.

System	No of sites compared	Capacity (m^3)	S1s (000)	S2s (000)	Total (000)	Ratio nos/m^3	Ratio kg/m^3*
Tanks	104	39,487	13,348	737	14,085	357	11.1
Cages	72	238,226	13,066	1,589	14,655	62	2.0

*Assumes average weight of S1 is 30 g and S2 is 50 g.

SURVIVAL AND HEALTH

Table 2 (column 13) illustrates the best figures available on overall survival of sea fish for the industry. Survival for the 1984, 1985 and 1986 smolt intakes was 86%, 70% and 74%, but the trend suggests that the figure for the 1987 smolts may well be about 66%. If 75-80% survival is assumed to be attainable, the additional losses are most likely to be attributable to two diseases. This is reflected in the number of cases of diseased fish submitted to the author's laboratory for examination. Furunculosis (Munro 1988) and pancreas disease (Munro et al. 1984) are by far the biggest causes of death. No other diseases cause comparable losses.

Furunculosis has, with increasing frequency, been found to be unmanageable, even if staff experienced in its diagnosis and treatment are at hand. The increasing appearance of multiple antibiotic resistance may leave the farmer with no treatments, in which case fallowing the site may be the only option or he may have to resort to much more expensive, possibly less palatable and toxic, chemotherapeutic agents. Site losses of up to 50% have occurred. The severity and chronic nature of the disease in older sea fish is a particular feature. Multiple sites within sea lochs and multiple year-classes within sites all contribute to the spread.

Pancreas disease is infectious, probably viral, and there is at present no treatment for it and no means of avoiding it (McVicar and Munro 1988). Often, its effects are slight but, in combination with other diseases, e.g. furunculosis or IPN virus carriers, or as yet poorly identified stress conditions, it can be very serious.

The large projected increase in production in 1989 at existing sites and no immediate relief from either disease give cause for concern that no improvement in survivals can be expected in the short term.

It has not been possible to obtain comparable figures for freshwater survival because of the large numbers of potential 2-yr-old smolts which are culled. However, there is no suggestion that infectious disease conditions of comparable gravity to the seawater scene are occurring in smolt rearing.

THE ENVIRONMENTAL IMPACT

Various criticisms are increasingly being levelled at salmon farming as it continues to grow. The absence of any formal planning control on new sites or a control strategy at existing sites are often highlighted, and it has been suggested that anomalies have arisen from having several agencies which do not have some powers of control. The interpretation of laws and regulations which were not specifically designed to regulate fish farming has also been cited as a cause for concern.

The Crown Estate Commissioners (CEC) are responsible for managing the sea bed on behalf of the Crown and thus for granting leases for marine fish farms. Although CEC has a duty to achieve good financial returns, it would not knowingly grant a lease where it thought environmental damage would occur. What constitutes damage and what constitutes acceptable environmental change are at the centre of this debate, with critics arguing that further expansion in some or many areas should stop because irreversible changes may be induced. Little evidence to support such claims has been produced thus far, although the environmental consequences of the use of tributyltin compounds (TBTs) on fish cage nets to stop fouling played a significant part in the banning of this material in fish farms and on small boats. The use of a dichlorvos-based pesticide to control lice on the skin of salmon is under increasing attack because of fears of its effects on wild crustaceans which are important for fisheries and as part of the food web.

Because most salmon farms are in important tourist areas, a criticism that loss of visual amenity is occurring has been made. A response through an industry-sponsored code of practice has recommended the use of materials harmonizing with the environment. It has already had useful results. In general, tourists tend to be more curious than critical of farms, and it is often local incomer residents who are most concerned about the visual intrusion of farms.

As the number of marine sites increases, shellfish farmers, commercial fishermen and pleasure boat interests are finding cage sites intruding on their interests. As a result, an increasing number of applications for new sites are being refused by the CEC because of the representations of such interests.

Freshwater planning applications for smolt production are subject to discharge consents from the appropriate regional River Purification Boards (RPB). The calculated annual discharge of phosphorus is of critical importance in freshwater lochs. Levels of phosphorus, nitrogen and organics all figure in discharge consents to rivers. What is an acceptable level of discharge in marine environments has yet to be decided by RPBs. However, local environmental parameters figure in all decisions. Planning approval for new smolt sites and for any land-based developments supporting sea sites is in the hands of Regional Planning Authorities. Differing and changing attitudes of the planners in these different authorities have also added to controversy.

Wild salmon fishery interests are acutely concerned that escapes from salmon farms and the diseases of farmed salmon may both have detrimental effects on wild salmon. No proof of such effects exists but these interests counsel conservative policies, i.e., stronger regulation on fish farming, until it is certain that such fears can be discounted. Shooting of predators, in particular seals, is also a cause of much concern. However, other deterrents, nets and sonic scarers, have not proved effective in all circumstances. If the farmer is to protect his stock from what is aberrant behavior compared with the great majority of seals, then shooting is sometimes necessary until other means of deterrence can be found.

THE ECONOMIC AND SOCIAL IMPACT

Figure 4 shows the level of direct employment achieved by the industry. These figures are very large in terms of the remote rural communities where the fish are farmed. Apart from subsistence crofting, the fish farm is often the only source of employment. In social terms, its growth has been a stabilizing factor arresting the drift of young people to cities and, in some areas, causing population growth.

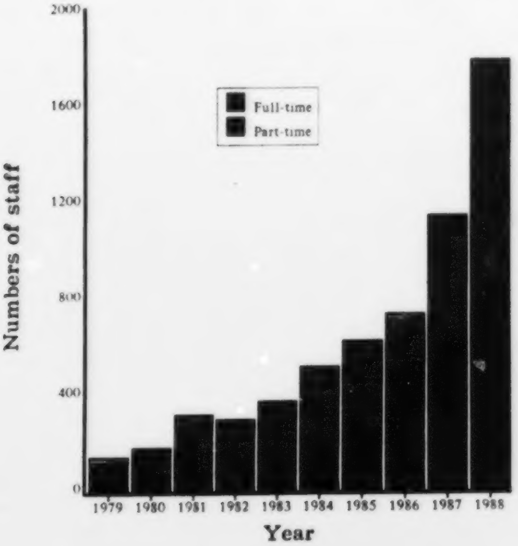

Fig. 4. Manpower directly employed in Scottish salmon farming 1979-88.

Jobs arising directly from the growth of the industry are possibly as high as three to four times direct employment although their effects are much more widely distributed. They arise from feed companies building plants mostly in Scotland and from the associated distribution chain; from the use of significant quantities of raw materials, including fish meal of UK origin; from British manufacturers, after rather a slow start, contributing an increasing share of the equipment supplied to the industry; and from processing and value-added products. Specialized plants have been built for processing salmon into fillets and steaks for fresh, controlled atmosphere and frozen packs, for smoking salmon and for a variety of other foodstuffs, including convenience meals and special and novel products. Increasingly, processing is seen as a means of adding value to more of the product and as a means of persuading the customer to eat more salmon.

ASPECTS OF ECONOMIC STRUCTURE IN THE INDUSTRY

SEA OPERATIONS

Analyses of the scale of production by site reveal a large range (Table 1). Examination of site production at the lower end over several years shows the greatest increases. These smaller producers appear to need to reach 50 t annually to achieve an adequate income. The biggest sites also appear to be growing, and it may be speculated that earlier cautions about risks from weather, algal blooms and disease have been discounted. However, the disease mortalities in 1987 and 1988, when some of the biggest sites suffered repeated outbreaks of furunculosis, sounded a warning.

A number of explanations of this size distribution have been advanced by Shaw (1989). Some are economies of scale associated with the operation of larger sites. Table 6 shows hypothetical cost structures for cage sites of 50, 200 and 500 t annual production. Although real costs may vary by ±30%, these figures suggest modest economies over 50-200 t, with somewhat less above 200 t. Several factors may restrict expansion to this scale, including the natural disasters already mentioned, physical dimensions of the site and limitations of the management team, ranging from site management to product selling.

Up to the present time, all systems have been operating under a favorable ex-farm selling price of about £4000/t, allowing both high and low cost producers to operate side by side.

Table 6. Comparison of annual operating costs at three levels of production near Scottish conditions (after Shaw 1989).

	Annual production (tonnes)		
	50	200	500
	£	£	£
Smolts	27,083	108,333	270,833
Smolt transport	2,083	8,333	20,833
Feed (ex works)	60,000	240,000	600,000
Feed transport	2,000	16,000	40,000
Salaries			
manager	18,000	18,000	18,000
assistant	-	15,000	15,000
labourers	7,500	22,500	45,000
Services	750	3,000	7,500
Consumables	1,500	6,000	15,000
Crown estate levy	2,500	10,000	25,000
Maintenance	8,120	15,360	32,080
Insurance	5,700	22,800	57,000
Annual Operating Costs	135,236	485,326	1,146,246
Working Capital	6,762	24,266	57,312
Fixed Capital	50,750	96,000	200,500
	192,748	605,592	1,404,058
Cost per ton	3,855	3,028	2,808
Cost per kilo	3.86	3.03	2.81
Cost per lb	1.75	1.37	1.27

Assumptions

Cage type	12 x 12 x 7 m
Food conversion ratio (FCR)	2
Average harvest size (kg)	3
Mortality smolt-harvest (%)	20
Stocking density (kg/m^3)	15

Working capital 10% interest charge on 50% of annual operating cost
Fixed capital 25% of fixed capital to cover interest/depreciation

However, as production continues to increase and prices fall, the cost disadvantages of small sites will become more apparent and, in consequence, few small-scale new developments are likely. This does not necessarily mean the extinction of existing small sites; debt repayments will be less or nil and efficiency will increase with experience. There is, however, pressure from bigger operators to buy out small sites with potential for expansion, again emphasizing the trend to larger scales of operation whether at site or through multi-site operation.

The larger multi-site operators still dominate production, although their proportion is dropping each year. The largest, Marine Harvest, a Unilever subsidiary, will have produced nearly 5000 t in 1988 from more than 20 sea sites in Scotland, and is the biggest producer of salmon in the world. This company has produced many of the managers for other operators owing to its far-sighted schemes of training staff, and it has also pioneered several technical developments. The larger businesses have advantages of scale, e.g. in terms of discounts for bulk buying of food and hardware and economies of labour. They can also afford specialist staff, e.g. for development projects and for health care.

Despite certain trends towards bigger units the number of smaller companies has been growing. A major reason has been a European Commission backed initiative directed at the disadvantaged Western Isles, comprising Lewis, Harris, the Uists and Barra. About 30 farms, most of which still produce less than 50 t, have been established with capital support amounting to 70% in most cases. Substantial business and technical support was also provided by the Highlands and Islands Development Board. This Board, a Central Government funded agency, has provided more than £25 million over the last 20 yr by way of grants, loans and other inducements to salmon farmers. It is estimated to have provided approximately 30% of the capital costs of all salmon farming development in Scotland.

Another area of small farm development has been the Northern Isles of Shetland and Orkney. Again, financial and other support has been significant. Unique laws in these areas have ensured that local interests have been allowed to develop fish farming without competition from the large, mainland operators.

A reason for the survival of small salmon farming businesses advanced by Shaw (1989) is the existence of wholesale fresh fish markets in the UK. Wholesale customers who buy on a spot basis in large or small quantities as available, and who pay quickly, are easy to sell to and, as a consequence, marketing costs to producers are low. There has been no need for a stronger and therefore more expensive marketing infrastructure within such farms' operations. Small operators have been able to despatch small quantities to markets to suit their convenience, in the knowledge that a market always existed for their fish. Unlike Norway, which seeks to export most of its production, perhaps 60% of UK salmon goes for home consumption, thus offering a strong local market for these farms. This system will continue to serve the small producer as long as there is no strong downward pressure on the price. Some restructuring, however, seems inevitable as production continues to increase world wide, making economies of a larger scale of operation necessary. This may be through merger, group marketing or buying of companies.

FRESHWATER OPERATIONS

Generally, most large companies have run integrated operations, whereas many small operators either produce smolts or buy them for ongrowing. There has, however, been a trend for a few smolt operations to become very big producers in recent years as the number of small sea farmers, e.g. in the Northern Isles where fresh water is scarce, has increased. Smolt production has lagged behind demand in most years, thus ensuring a very good price of about £1.30-1.50/smolt. Table 3 shows the grouping of sites by their scale and expected scale of production, in which a 50% increase in production is anticipated in 2 yr. The 1990 estimate of 31 million smolts represents about 57,000 t of fish if we assume a 66% survival and an average fish weight of 2.8 kg.

Although increasing the scale of operations is likely to offer economies, many special factors can affect costs. For example, combining cage and hatchery operations offers considerable economies: water temperature varies considerably between sites and will influence the costs of production of 1-yr smolts;

some large farming estates have integrated a smolt unit in their land farming operations utilizing existing land and water at less than general costs.

TRADE AND OTHER ASSOCIATIONS

Most fish farmers are members of the Fish Farming Section of the National Farmers Union of Scotland (SNFU). The SNFU represents the farmers' interests in negotiations and lobbying with the national government, particularly when laws are being drafted or changed. In addition, the salmon farmers are represented by the Scottish Salmon Growers Association (SSGA) and the Shetland Salmon Farmers Association (SSFA). These trade organizations raise substantial incomes from levies on production, which they use for generic product promotion, developing codes of conduct (e.g. on product quality and environmental issues) and, more recently as their funding has grown, commissioning research. Subjects for research include disease control, effects of wastes and their disposal, nutrition and product quality. In 1988, the SSGA and the SSFA jointly formed the Scottish Salmon Farmers Marketing Board, a body to promote the sale of farmed salmon at home and abroad.

QUALITY

A quality scheme is sponsored by the SSGA and the SSFA. Its purpose is to encourage the production and marketing of high quality farm-reared Scottish salmon. Wholesalers and ultimately retailers and consumers are then provided with an assurance that a consistent level of quality and service will be maintained so that they may, with confidence, buy salmon that carries the Scottish Salmon Quality Mark. Administration and operation of the scheme is delegated by the SSGA to Scottish Quality Salmon Ltd. and by the SSFA to Shetland Seafood Quality Control Ltd.

The scheme is an accredited member of Food from Britain's Quality Certification Scheme and so the Scottish Salmon Quality Mark is endorsed by the Quality British Food Mark, the use of which is controlled by the Quality Council of Food from Britain. The scheme lays down specific quality standards for salmon which have been farm reared in Scotland for the table. It emphasizes the need for high standards to be maintained on farms and in packing stations and it requires that standards of quality performance will be monitored by an independent inspection service. Participation is voluntary and membership is restricted to members of the two associations.

MARKETS

Reliable information on where Scottish farmed salmon is consumed is scarce. Shaw and Muir (1987) reported that 67% of Scottish production was sold in the UK market in 1986, but it is probable that this proportion has dropped to nearer 50-60% in 1988. Thus, UK consumption has expanded in spite of continued Norwegian farmed and wild Pacific imports. It is concluded that Scottish farmed salmon has expanded the market rather than acted as a substitute for imports. Traditional smoked salmon, until recently, accounted for up to 60% of consumption. However, consumption of fresh salmon is now increasing because housewives are gaining more confidence in cooking salmon and because of the increasing popularity of convenience dishes containing it.

Exports are mostly to France, a traditional market. However, many other countries now receive Scottish farmed salmon, including most members of the European Community, Switzerland, the USA, Canada and Japan. There is considerable optimism in the industry that consumers will eat more salmon and that more consumers will be found. However, everyone is conscious of too rapid growth of production world wide. Excess capacity could arrive before promotion and product development encourage consumers into greater consumption. Shaw and Rana (1986) conclude that such an occurrence will not favor the many small producers dependent on traditional markets. The probable outcomes are already becoming evident in Scotland, namely takeovers of less successful companies, joint marketing schemes linking some smaller producers with larger ones and the creation of regional marketing companies for some smaller producers.

More farms or associations of farms operate plants for gutting, grading and packing. There is, however, little attempt at vertical integration between production and secondary processing. Such secondary processing, e.g. smoking, has developed separately, sometimes in association with the processing of other fishery products which are numerous in this area.

CONCLUSIONS

This is a period of very rapid increase in production, both in Scotland and wherever else salmon are farmed. Production systems, markets and marketing are all in periods of transition. It is probable that further significant changes will occur before any great stability occurs in this industry. After pursuing rather individualistic courses, Scottish salmon farmers are clearly recognizing that intensification of competition can be expected. Two strong trade associations and a joint marketing organization exist and they are developing a strong generic brand image for Scottish salmon. A degree of restructuring of the industry is already under way in response to anticipated pressures. The extent to which this will continue will depend on market forces.

REFERENCES

Anon. 1979-1989. Annual reports of the production of Scottish fish farming. Department of Agriculture and Fisheries for Scotland, Edinburgh.

Johnstone, R. 1989. Maturity control in Atlantic salmon - a review of the current status of research in Scotland. In Proc. Satellite Symposium on Applications of Endocrinology to Fish Cultivation. Almunecar, Spain.

McVicar, A. H., and A. L. S. Munro. 1988. Further results in the study of the aetiology of pancreas disease of farmed Atlantic salmon. Int. Counc. Explor. Sea C.M./F:35, 8 p.

Munro, A. L. S. 1988. Furunculosis in farmed Atlantic salmon in Scotland. Dept. Agric. Fish. Scotland, Aquacul. Info. Ser. 1: 7 p.

Munro, A. L. S., A. E. Ellis, A. H. McVicar, H. A. McLay, and E. A. Needham. 1984. An exocrine pancreas disease of farmed Atlantic salmon in Scotland. Helgol. Meeresunters. 37: 571-586.

Munro, A. L. S., and I. F. Waddell. 1987. Growth of salmon and trout farming in Scotland, p. 246-263. In R. S. Bailey and B. B. Parrish [ed.] Developments in fisheries research in Scotland. Fishing News Books Ltd.

Shaw, S. A. 1989. The economics of Scottish salmon farming. Organisation for Economic Cooperation and Development Extended Meeting on Aquaculture, Paris.

Shaw, S. A., and J. F. Muir. 1987. Salmon: economics and marketing. Croom Helm.

Shaw, S. A., and J. Rana. 1986. Markets and marketing practices for Scottish grown salmon. Inst. Retail Studies, Univ. Stirling.

SALMONID MARICULTURE IN ATLANTIC CANADA AND MAINE, USA

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ABSTRACT

Saunders, R. L. 1991. Salmonid mariculture in Atlantic Canada and Maine, USA, p. 21-36. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

Several attempts were made in the 1960's and early 1970's to establish salmonid mariculture in the study area, Atlantic Canada and Maine. Some persisted for a time but none of those continues today. Lethal winter-sea temperature was the chief constraint. The first successful year-round sea-cage culture of Atlantic salmon and rainbow trout began in 1978 in the southwestern Bay of Fundy of New Brunswick and Maine. Production of Atlantic salmon in New Brunswick and Maine reached 3864 tonnes in 1988. Although lethal winter-sea temperature precludes year-round salmonid culture in sea cages in much of the study area, significant production has also begun in parts of Nova Scotia and Quebec. There are many areas with adequate protection from heavy seas but few areas in the northeast do not have regular or frequent episodes of lethal winter-sea temperature. Of the various constraints to expansion of salmonid mariculture in the northeast (lethal winter-sea temperature, diseases, parasites and predators, plankton blooms, early sexual maturation and a chronic shortage of smolts), only lethal temperature is currently preventing rapid expansion of the industry. Lethal temperature could be avoided by practising seasonal production, use of land-based sites supplied with water of suitable temperature, locating growout farms in bays with thermally stratified water, use of thermal effluent and development of genetically altered, freeze-resistant strains. The areas with suitable environmental conditions are expected to increase production significantly during the next few years. This increased production, together with application of suitable technology to avoid lethal temperature in other areas, now considered only marginally acceptable, are expected to result in the northeast becoming a major salmonid producer.

RÉSUMÉ

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Dans les années 1960 et au début des années 1970, on a tenté à plusieurs reprises d'implanter la mariculture du saumon dans la zone considérée, soit le Canada atlantique et le Maine. Certaines des exploitations d'élevage ont subsisté quelque temps, mais aucune d'elles n'a survécu jusqu'à ce jour. La température létale de la mer en hiver a été le principal obstacle à cette entreprise. La première expérience réussie d'élevage du saumon de l'Atlantique et de la truite arc-en-ciel en cages marines à longueur d'année au Nouveau-Brunswick et dans le Maine a débuté en 1978 dans le sud-ouest de la baie de Fundy. La production de saumon de l'Atlantique dans cet État et cette province atteignait 3 864 tonnes en 1988. Bien que la température létale de la mer durant l'hiver empêche de pratiquer à longueur d'année la salmoniculture en cages marines dans une bonne partie de la zone considérée, la production a démarré à une échelle non négligeable dans certaines parties de la Nouvelle-Écosse et du Québec. On recense de nombreux endroits bien protégés contre la grosse mer, mais il en est peu, dans le Nort-Est, dont la température hivernale de la mer n'atteint pas régulièrement ou fréquemment des niveaux létaux. Des divers obstacles à l'expansion de la mariculture du saumon dans le Nord-Est (température létale freine encore une rapide croissance de l'industrie. On pourrait contourner cette difficulté en pratiquant une production saisonnière, en recourant à des installations d'élevage terrestres alimentées en eau à température adéquate, en installant les piscicultures dans des baies à stratification thermique, en utilisant des effluents thermiques et en produisant, par des modifications génétiques, des souches résistant au gel. On s'attend à ce que la production augmente considérablement, au cours des prochaines années, dans les régions qui offrent un milieu d'élevage favorable. Cette production accrue combinée à l'application d'une technologie permettant de contourner le problème des températures létales dans les régions qui ne sont pas, pour le moment, tout à fait adéquates devraient faire du Nord-Est un grand producteur de salmonidés.

INTRODUCTION

Marine culture of salmonids in the study area (Atlantic Canada and Maine, Fig. 1) began in the 1960's with the first commercial production at a land-based site, Sea Pool Fisheries, near Clam Bay, Nova Scotia, from 1969-72. Maine Salmon Farm reared coho salmon (*Oncorhynchus kisutch*) and rainbow trout (*O. mykiss*) during several years in the 1970's using thermal effluent from an electrical generating station in Wiscassett. Cape Breton Marine Farming (Cape Breton Development Corporation) produced rainbow trout for 12 yr using sea cages from May to December near the seaward entrance to Bras D'Or Lake. Successful marine production of Atlantic salmon (*Salmo salar*) and rainbow trout began in southwestern New Brunswick (Fundy Islands area of lower Bay of Fundy) in 1978 with the first production, in 1979, of 6 metric tonnes (MT). There is now a significant industry in southwestern New Brunswick and adjacent Washington County, Maine, with 49 marine sites having produced 3864 MT of Atlantic salmon and a smaller amount of rainbow trout in 1988 (Tables 1, 2). The Fundy Isles area of the lower Bay of Fundy (Fig. 2) is suitable for salmonid mariculture owing to availability of adequately protected sites with acceptable thermal regimes, the two prime requisites for year-round salmonid mariculture. This relatively small area not only has excellent environmental conditions resulting in superior growth of salmonids, but also has the advantage of being relatively close to one of the world's largest potential markets, the North American Northeast.

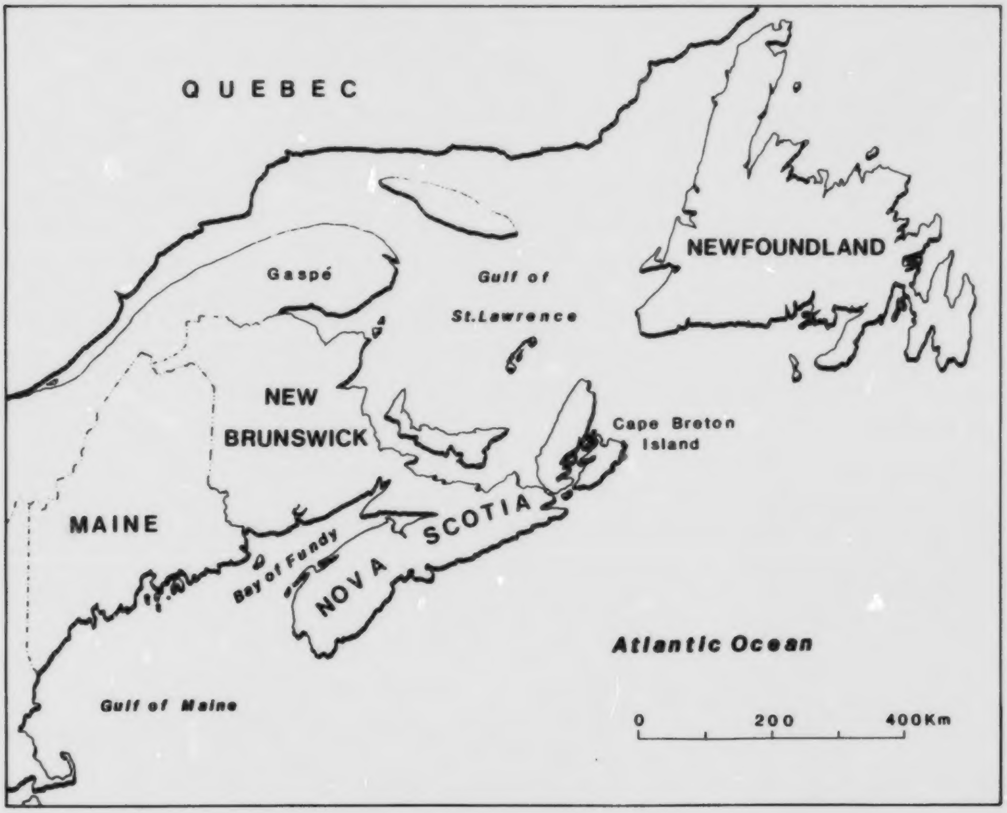

Fig. 1. Map of salmonid mariculture study area, Atlantic Canada and Maine, USA.

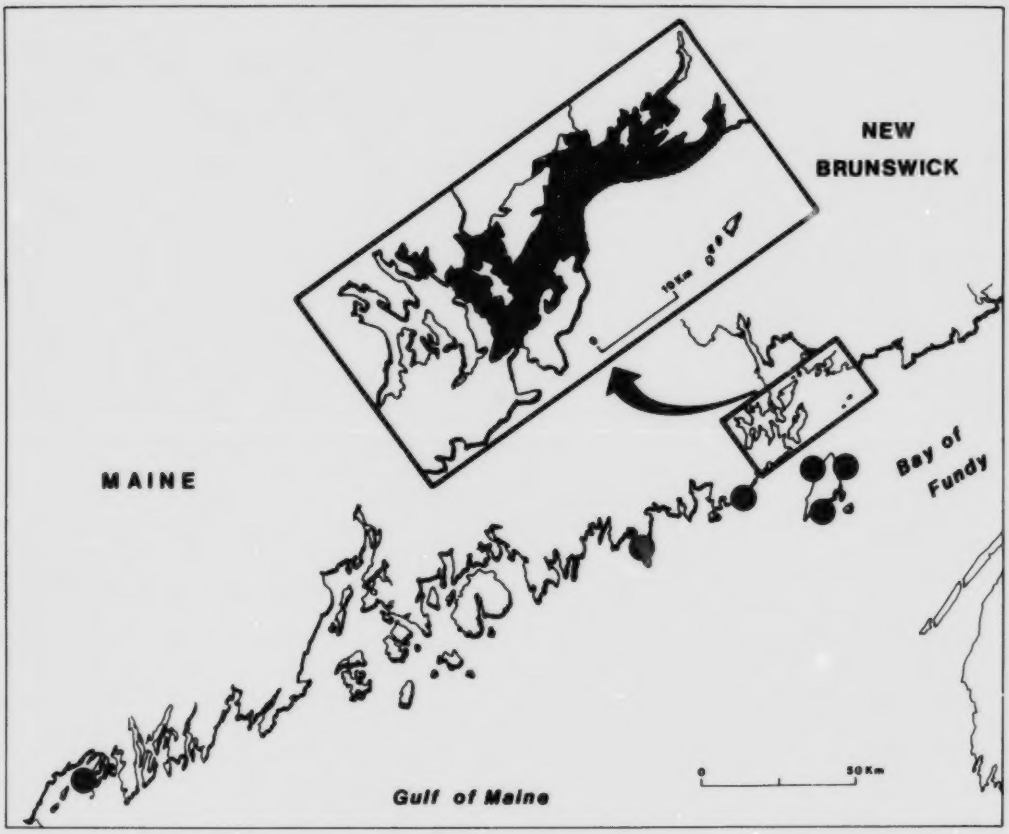

Fig. 2. Lower Bay of Fundy-Gulf of Maine region showing areas of major salmonid mariculture activity in southwestern New Brunswick and northeastern Maine. Dots indicate locations of one or more cage sites; shaded area shows major concentration of marine growout sites in southwestern New Brunswick and northeastern Maine.

Altough there are many other potential marine salmon farming sites in Atlantic Canada and Maine with adequate protection from heavy seas, there are few places that do not have regular or frequent episodes of lethal winter sea temperature. Indeed, the first attempts to overwinter salmonids in sea cages in eastern North America were made at Vinalhaven Island, Maine, Arichat and St. Margaret's Bays, Nova Scotia and at the St. Andrews Biological Station in New Brunswick. In each case, the fish experienced lethal winter temperature and this discouraged further attempts for some time. This presentation describes the present status of the salmonid mariculture industry in the Canadian Atlantic Provinces and in the State of Maine, the environmental and other constraints which have, so far, limited its growth beyond present areas of activity and the strategies and technologies that could make possible its expansion to areas that are not suitable with existing technology.

RECENT PRODUCTION - ATLANTIC SALMON

Production of Atlantic salmon in Atlantic Canada and Maine was about 1570 MT in 1987 and 3860 MT in 1988 (Table 1), with landed values of about $22 and $48 million, respectively,

Table 1. Atlantic salmon mariculture activities and production in Maine and the Canadian Atlantic Provinces in 1987 and 1988.

Location	Number of sites 1987	Number of sites 1988	Production (MT) 1987	Production (MT) 1988
Maine	7	14	273	364
New Brunswick	32	36	1300	3500
Nova Scotia	6	8	31	66
Prince Edward Island	-	-	-	-
Québec	1	1	10	35
Newfoundland	5	5	-	11
Totals	51	61	1614	3976

Table 2. Rainbow trout mariculture activities and production in Maine and the Canadian Atlantic Provinces in 1987 and 1988.

Location	Number of sites 1987	Number of sites 1988	Production (MT) 1987	Production (MT) 1988
Maine	4	7	11	60
New Brunswick	14	7	33	15
Nova Scotia	5	5	189	265
Prince Edward Island	2	3	9	16
Québec	-	-	-	-
Newfoundland	-	-	-	-
Totals	23	20	242	356

at prevailing prices. The number of marine production sites in Maine doubled between 1987 and 1988, most of these in the northeast, in the same marine circulation as the New Brunswick production area in southwestern Bay of Fundy (Fig. 2). Maine production is expected to increase sharply in 1989, reflecting the greater number of smolts that were put out in 1988. The small increase in number of cage sites in New Brunswick between 1987 and 1988 was owing to a provincial moratorium on leases for new sites because of possible conflict with traditional (herring weir, lobster and scallop) fisheries, unknown influences of cage rearing on the environment, uncertainty as to the safe or optimum number of farms for a given area and to allow private smolt producers to catch up with demand. Nevertheless, the N.B. production more than doubled between 1987 and 1988. This reflected increased smolt supplies from the several private operators which had finally come close to meeting the demand for smolts. The continued increased smolt production in 1988 and expected production in 1989 should result in further dramatic increases in N.B. production of market-sized (3-5 kg) salmon in 1989-90 and beyond. The recent removal of the moritorium on leases for new cage sites should lead to further increases in production.

Nova Scotia is in an earlier stage of development of the salmonid mariculture industry, having farm sites in the lower mainland and Cape Breton Island (Fig. 3) with production of 31 and 66 MT of salmon in 1987 and 1988, respectively (Table 1). The doubling of production, by three farms in mainland Nova Scotia and five in Cape Breton Island, also reflects an increase in the supply of smolts. Greater numbers of smolts put out in 1988 and expected in 1989 should result in rapid increases in production of salmon in Nova Scotia. In Prince Edward Island, there has been no marine production of Atlantic salmon although there may be one or more onshore (pumped brackish water) sites beginning in 1989.

The province of Quebec has one onshore facility supplied with brackish and fresh water from wells (Fig. 4, 5). Production more than tripled, from 10 to 35 t, between 1987 and 1988. The producing company is vertically integrated with its own smolt production, processing and marketing facilities. Owing to increased numbers of smolts put in seawater in 1988 and planned for 1989, market production should increase sharply in the next few years.

Newfoundland has five salmon growout sites in two inlets which have thermal stratification allowing salmonids to overwinter in submerged cages in water of acceptable temperature overlain by an ice cover which does not threaten destruction of the cages (Fig. 6). Production in 1988 would have been much greater than 11 MT had it not been necessary to destroy the stock of salmon following an outbreak of furunculosis. Unfortunately, the 1988 smolts which had been put in sea cages and juveniles in the hatchery (potential 1989 smolts) were also destroyed for the same reason. A new stock of smolts should be available in 1990, with marine production resuming in 1991.

RECENT PRODUCTION - RAINBOW TROUT

Production of rainbow trout in Maine and the Canadian Atlantic Provinces, although at lower levels than for Atlantic salmon, has been significant during the 2 yr for which data are provided (Table 2). Rainbow trout production in the North American study area, as in Norway and other countries with salmonid mariculture industries, grew rapidly during early years of the industry and was later eclipsed by increasing production of salmon. This is exemplified by the industry in southwestern New Brunswick which had much reduced production of rainbows in 1988 in comparison with 1987. On the other hand, rainbow production in Maine and Nova Scotia increased during this period. These changes are explainable on the basis that Atlantic salmon smolts were not generally available for mariculture activities; most smolts produced by federal government rearing stations are used for public fisheries. These smolts are more difficult and costly to produce than juvenile rainbows of a size capable of living and growing well in seawater. Smolting in Atlantic salmon and other salmonid species provides these fishes with the physiological capability of surviving direct transfer from fresh to seawater and the metabolic capability for rapid growth in the marine environment. The smolting process, if it does occur in the stocks of rainbow used in mariculture, is much less clearcut and stringent than in Atlantic salmon. Consequently, whereas Atlantic salmon must have achieved a clearcut smolt status (usually completed in the spring)

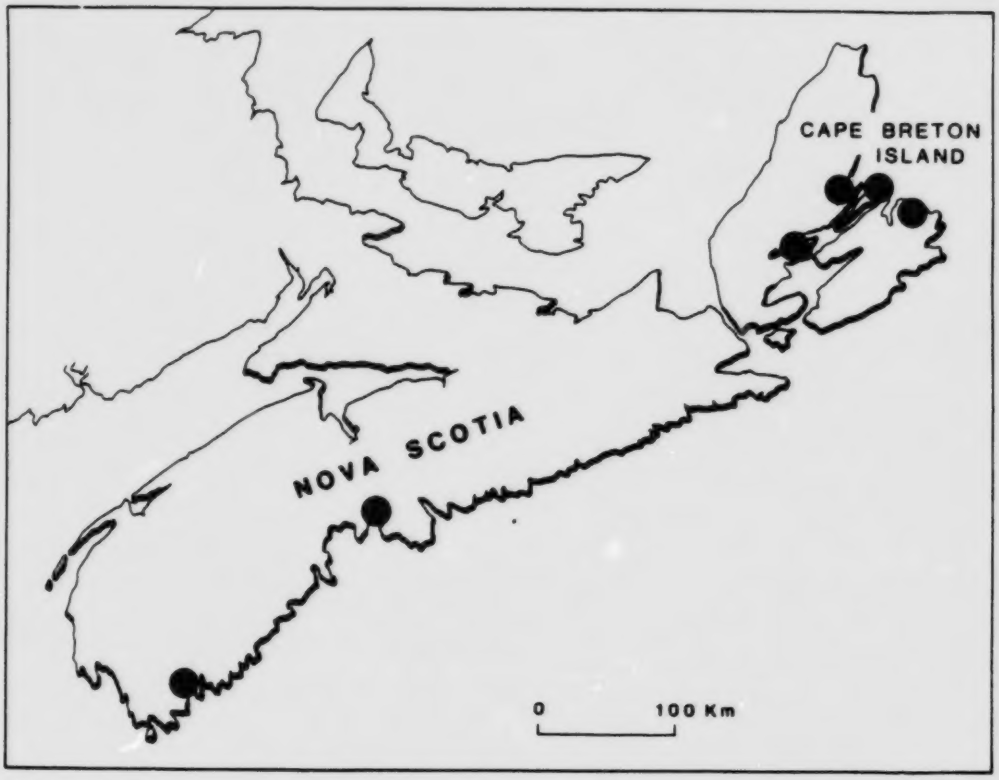

Fig. 3. Salmonid mariculture locations in Cape Breton and mainland Nova Scotia. Each location has one or more farm sites.

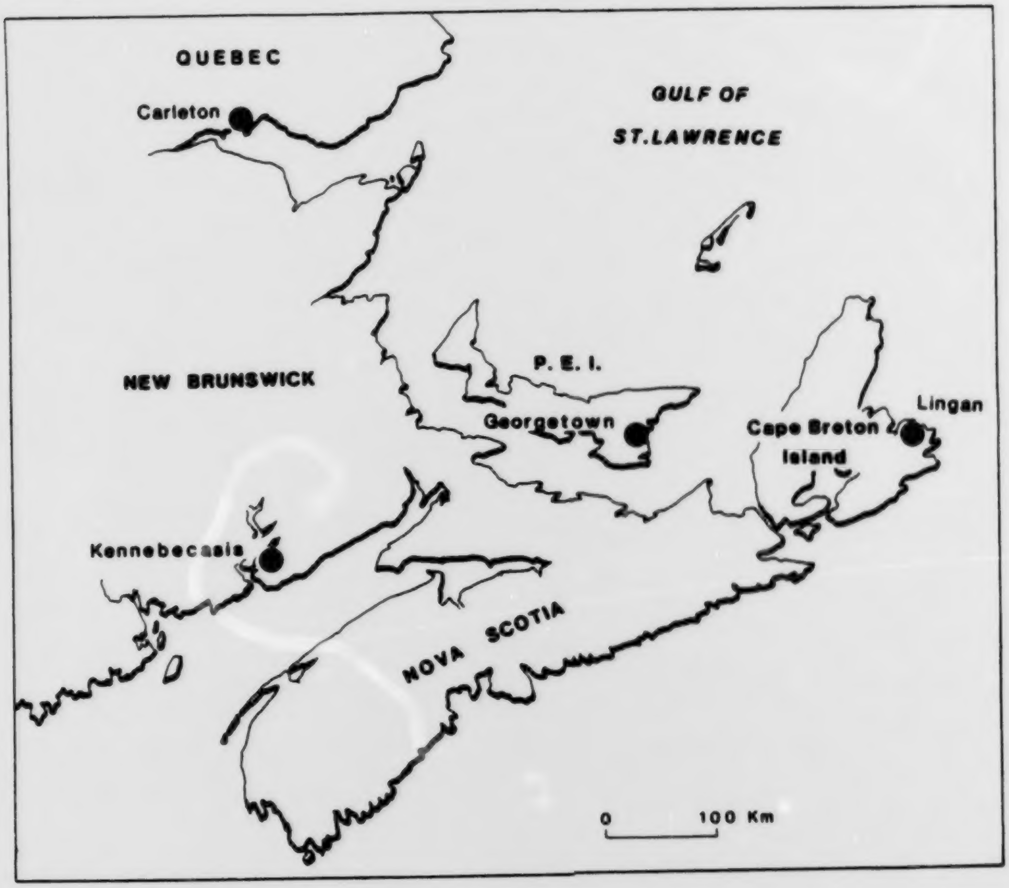

Fig. 4. Locations of land-based salmonid mariculture in Quebec, New Brunswick, Prince Edward Island and Nova Scotia.

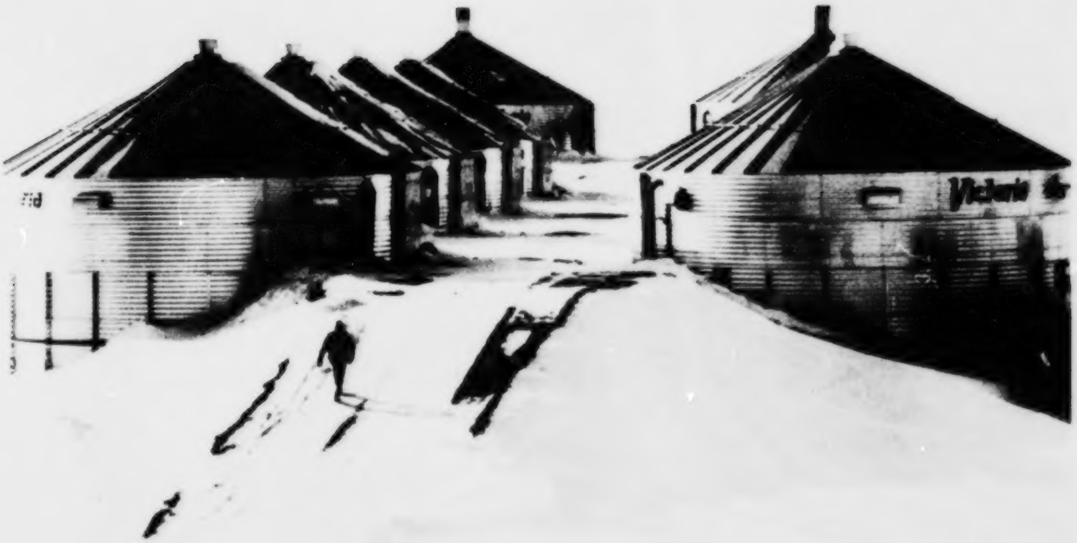

Fig. 5. Land-based salmon farm in Carleton, Quebec. Photo courtesy of Bill Boudreau, Baie des Chaleurs Aquaculture Ltd. and Bulletin of the Aquaculture Association of Canada.

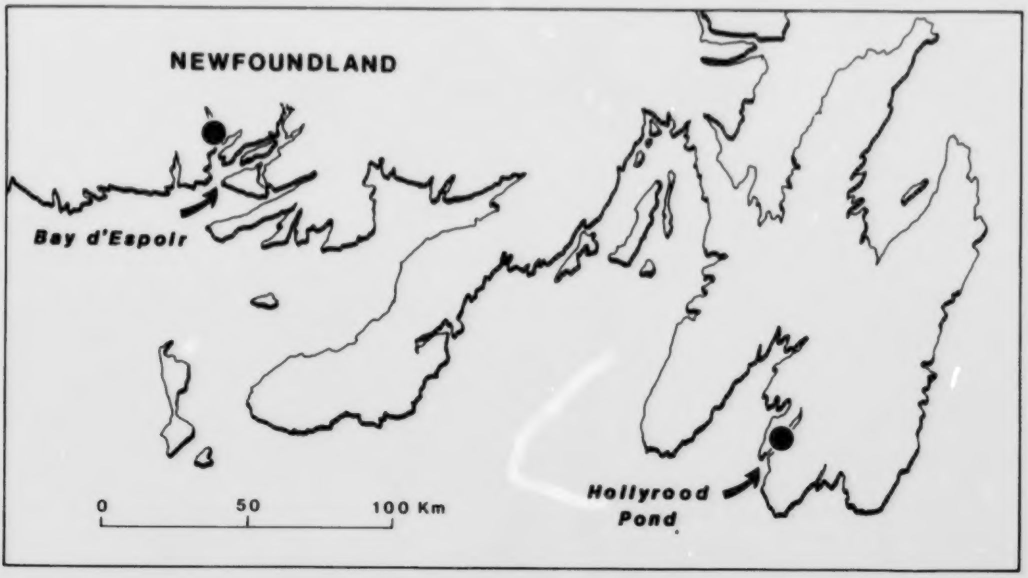

Fig. 6. Salmonid mariculture sites taking advantage of thermal stratification in southern Newfoundland bays.

before they are capable of living and growing in seawater, rainbows develop this capability younger and at smaller size and can usually be transferred as soon as they reach suitable size, regardless of season. In the North American study area, there has been a chronic shortage of Atlantic salmon smolts. Since there was at first no demand for smolts, there was no private sector smolt production industry. In the early stages of salmonid mariculture in the study area, only governments were producing salmon smolts and these were for restoration, stock enhancement and other public fisheries. Only recently have private smolt producing companies been able to come near meeting the demand for smolts by the rapidly growing salmon mariculture industry.

Another factor responsible for the shift from rainbows to Atlantic salmon is the higher market price for salmon. This situation may be a result of marketing strategies, with most emphasis on Atlantic salmon based largely on tradition and public acceptance. However, few diners can distinguish between well prepared rainbows and Atlantic salmon of comparable size. Therefore, although Atlantic salmon are gradually replacing rainbows and are the cultured salmonid of choice in the study area, this trend could change if local conditions favor culture of rainbows or other salmonids, e.g. brook trout (*Salvelinus fontinalis*) and Arctic charr (*Salvelinus alpinus*) or, more likely, if marketing efforts are directed to these other species. However, it is likely that Atlantic salmon will continue to be the cultured salmonid of choice owing to the present market demand and the more favorable price to growers. Newfoundland salmon farmers will grow sterile rainbows in 1989 and 1990 at least, until their new stock of disease-free Atlantic salmon comes into production.

ENVIRONMENTAL CONSTRAINTS

As previously mentioned, it is not for lack of incentive and efforts to establish salmonid mariculture in the North American Northeast that the industry in this area is far behind those of the world leaders in salmonid mariculture, Norway and Scotland. Early efforts in New Brunswick, Nova Scotia and Maine established the reality of lethal winter temperatures in seawater. Atlantic salmon, brown trout (*Salmo trutta*), rainbow trout, brook trout and Arctic charr die in seawater at temperatures of ca. -0.7 to -1.0°C (Fletcher et al. 1988). In most coastal areas of Maine and the Canadian Atlantic Provinces, nearshore seawater temperatures fall well below the lethal level each winter. The freezing point of seawater at a salinity of 30 o/oo is -1.8°C, well below the lethal level for salmonids. Fletcher et al. (1988) point out that salmonids can resist freezing at temperatures below their normal freezing (lethal) levels provided they do not come into contact with ice. However, it would be unreasonable to expect salmonids to survive in marine locations where there are frequent or sustained periods with seawater temperatures near or below the lethal level. The common occurrence of sea ice in most nearshore areas in Atlantic Canada and Maine attests to the reality of lethal temperature for salmonid fishes in this area. Even in southwestern New Brunswick and northeastern Maine where salmonid mariculture shows most promise, sea temperatures have fallen to the 0 to +2°C range nearly every winter since the industry started in 1978-79 (Saunders et al. 1983). However, we have been enjoying a period of relatively mild winters since 1978. Sea surface temperatures measured at the St. Andrews Biological Station during the 1960's and 1970's were lower than in more recent years; some years in the mid 1960's and early 1970's had monthly means lower than 0°C (Table 3). It is likely that such low means were comprised of many days with lethal (-0.7 to -1.0°C) temperatures. There have been notable examples of salmonid kills in New Brunswick and Nova Scotia owing to local conditions, even during winters with relatively mild temperatures (Saunders 1987). We have learned that it is unsafe to place sea cages in inlets too close to large intertidal areas where water is cooled very rapidly during tidal exchange, particularly if spring tides occur during extended periods with extremely low air temperature.

Lethal seawater temperatures are typical in much of northern New Brunswick, Nova Scotia, Prince Edward Island, Quebec and Newfoundland. Up to 1988, the only coastal area of Maine that has had consistent salmonid mariculture is near Eastport which, like the shore of southwestern New Brunswick, enjoys the influence of the extreme tidal exchange in the lower Bay of Fundy (Fig. 2). It is likely that otherwise suitable marine cage sites in southwestern Maine and southwestern Nova

Table 3. Monthly mean surface temperatures of seawater at the Biological Station, St. Andrews, New Brunswick, 1964-87. No temperatures taken from October 1985-April 1986. Data from 1964-79 from Lauzier and Hull (1969). Subsequent data from I. Perry (pers. comm.). Table reproduced from Saunders (1989).

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1964	1.8	1.3	1.7	3.4	6.7	8.5	10.8	11.7	11.4	10.1	7.2	3.3	6.5
1965	1.1	0.5	1.2	3.2	6.2	8.7	10.9	12.1	11.7	9.5	6.4	3.8	6.3
1966	1.8	0.9	1.9	3.8	6.1	9.1	11.2	12.3	11.9	9.9	7.9	5.1	6.8
1967	2.5	0.3	0.2	2.3	5.0	8.5	10.6	11.8	11.8	10.4	7.7	3.9	6.3
1968	0.3	-0.2	0.8	3.8	6.5	9.4	12.3	12.7	13.1	11.7	7.9	4.6	6.9
1969	2.3	1.8	1.9	4.2	6.8	9.9	12.1	13.9	13.3	10.8	8.7	5.5	7.6
1970	2.0	1.5	2.1	4.1	8.2	10.1	13.3	13.9	12.6	11.3	8.7	3.8	7.6
1971	0.9	-0.1	1.5	4.0	7.8	10.5	13.4	14.0	13.6	12.0	9.0	4.7	7.6
1972	1.9	0.3	-0.1	2.1	7.1	10.2	12.0	13.3	12.9	10.6	7.1	3.5	6.7
1973	1.2	0.8	1.6	4.4	6.9	9.1	12.3	14.3	12.7	11.0	8.1	5.8	7.4
1974	2.8	1.3	1.7	3.4	6.2	9.8	12.3	13.7	12.8	10.2	8.1	4.8	7.3
1975	2.8	0.7	1.3	2.9	6.3	9.3	11.9	12.7	12.1	10.7	8.7	4.5	7.0
1976	1.4	1.6	2.8	5.7	8.9	11.8	13.9	15.0	14.4	12.1	8.1	4.2	8.3
1977	0.7	0.2	1.4	3.8	6.6	10.5	11.9	12.5	12.4	10.7	8.8	4.5	7.0
1978	1.9	0.5	1.8	2.7	7.5	9.9	12.3	13.7	12.8	10.9	8.4	4.7	7.3
1979	2.1	0.6	1.9	4.1	7.9	10.8	12.7	13.6	13.6	11.0	8.9	5.9	7.8
1980	2.7	1.0	0.8	4.4	6.8	9.3	11.5	13.6	13.0	10.3	7.3	4.1	7.1
1981	0.6	1.1	2.1	4.4	7.3	9.8	12.6	13.0	13.0	10.7	8.2	5.5	7.4
1982	1.8	1.1	1.5	3.4	7.2	9.6	12.0	13.1	12.8	11.0	9.3	6.1	7.4
1983	3.7	2.0	2.7	5.6	7.9	11.0	12.0	13.2	13.1	11.5	8.5	4.8	8.0
1984	2.0	1.5	1.5	3.3	6.7	10.2	12.6	13.2	12.5	10.7	8.4	5.8	7.4
1985	1.6	0.6	1.9	3.7	5.9	8.2	12.0	12.9	11.6	-	-	-	-
1986	-	-	-	-	7.2	9.4	12.2	13.4	12.5	10.5	7.3	3.8	-
1987	2.0	0.5	0.4	4.0	6.5	10.6	12.2	-	11.8	10.4	7.2	4.5	-

Scotia, where tidal amplitude is less, experience lethal sea temperatures, particularly in nearshore areas where local cooling can be greatest.

Why should the lower Bay of Fundy offer acceptable sea temperatures while areas farther to the south (SW Maine and SW Nova Scotia) have lower temperatures? This seeming anomaly is owing to the extreme tidal amplitude which results in strong currents and complete mixing. The great mass of well mixed water does not warm to higher or cool to lower temperatures during the annual cycle. In areas with lower tidal amplitude and with less mixing, there can be thermal stratification with surface waters reaching more extreme temperatures in winter and summer (-1.8 to +20°C). The relatively narrow annual thermal range in the Fundy Isles area (ca. 0 to +15°C) (Table 3) is much less than in areas somewhat to the south, and to the north particularly, where much wider ranges are common.

In addition to the thermal constraints and the chronic shortage of Atlantic salmon smolts already discussed, there are, and will continue to be, sporadic problems from diseases, parasites and planktonic blooms. Under balanced conditions in nature, most pathogens and parasites are held in check. Epizootics do occur in nature, often triggered by increased population density and natural shifts in the environment. Mass culture of any animal species results in behavioral stress from unaccustomed proximity to numbers of the same species. Suboptimal conditions of culture regarding temperature, dissolved oxygen, current velocity and accumulation of metabolic waste products compound stress and increase chances of infection and outbreak of diseases. Diseases likely to affect salmonids during marine culture are furunculosis, vibriosis and bacterial kidney disease.

Harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) are fish predators which pose a serious threat to salmonid mariculture. These intelligent mammals are attracted to salmonid farms where they exact chronic tolls of dead and injured fish by clawing them through the cage mesh. Occasionally, seals break into cages killing many fish and allowing others to escape. Seal predation will continue to be a serious menace to salmonid mariculture, particularly in areas where wild fish stocks are declining while seal herds increase in response to concerns about animal welfare.

Holding large numbers of salmonids in confined spaces also attracts parasites such as sea lice (*Caligus elongatus* and *Lepeophtheirus salmoni*). These copepods graze on the epidermis and mucus layers causing direct injury by exposing interior tissues and facilitating infection by water-borne pathogens. Most salmonid mariculture sites in the study area have low infestations of these ectoparasites. Farms in areas with strong tidal currents, as in SW Bay of Fundy, may be less affected by sea lice than where water movement is less. Low winter temperatures in the North American northeast are beneficial; sea lice largely disappear during winter (Hogans and Trudeau 1988).

A largely unknown, but possibly serious, environmental hazard to salmonid mariculture in the study area is plankton blooms which may be directly lethal or cause physical damage by fouling the gills of salmonids. There were massive losses of salmon and rainbow trout in the Faroe Islands attributed to a toxin from the dinoflagellate, *Gonyaulax excavata*, which bloomed at unusual levels. The episode occurred at summer temperatures (ca. 11°C) and was associated with a frontal boundary between warmer oceanic water and colder shelf water. There were serious losses in association with an extensive bloom of the alga, *Chrysochromulina polylepis* in Norway (Saunders 1988). An algal front moved northwards along the coast killing caged salmonids as well as marine fishes and invertebrates in its path. About 100 farms escaped the algal bloom by being towed into fjords which had brackish water and were not entered by the bloom. Fortunately, this bloom moved offshore and dispersed, ending the crisis, but only after many salmonid farms were affected and ca. 480 MT of salmonids were lost. Similar incidents have not been documented in Maine or Atlantic Canada, but the possibility remains in this area where blooms of *Gonyaulax* species are common.

Sexual maturation after one sea winter (grilse) is a serious constraint in marine culture of Atlantic salmon in Europe but is a less serious problem in Maine and Atlantic Canada. The lower incidence of grilse may be owing to low winter temperature as suggested by Saunders et al. (1983) or to genetic influence on age and size at sexual maturity in the salmon stocks being cultured. The former is more likely in view of the observation that the Saint John River stock of salmon, which has been sea ranched (released to migrate naturally in the NW Atlantic) as well as cage reared in SW Bay of Fundy, yields a much lower incidence of grilse from Fundy sea cages than from sea ranching (Saunders et al. 1983). It has been suggested that low winter temperature acting directly, or more likely through metabolic energy levels following reduced feeding, results in the fish making a physiological "decision" not to commence sexual maturation during or following a period of low sea temperature. Whereas free ranging Atlantic salmon appear to avoid sea temperatures below 4°C (Reddin 1985), those in Fundy sea cages experience 0 to 2° for 3 or 4 mo each winter (Sutterlin et al. 1981; Saunders et al. 1983).

OVERCOMING THE LETHAL TEMPERATURE CONSTRAINT

The single most serious obstruction in the way of further development of salmonid mariculture in Atlantic Canada and Maine is lethal winter temperature. Supply of salmon smolts was a serious constraint but this is rapidly changing with increasing output from a growing number of producers in the private sector. Although early sexual maturation as grilse continues to plague the European salmon mariculture industry, the problem is less severe in eastern North America, probably owing to low winter temperature. Moreover, a Salmon Genetics Research Program funded jointly by the Canadian Department of Fisheries and Oceans and the Atlantic Salmon Federation is addressing genetic aspects of age and size at sexual maturation in Atlantic salmon. Although salmonid nutrition is receiving much attention and there are opportunities for improvement, this factor is not inhibiting growth of the industry. Diseases, parasites and predators are, and will continue to be, problems in the northeast, but these factors will not prevent development of salmonid mariculture in areas which might be suitable were it not for lethal water temperature. What can be done, then, to overcome the obstruction posed by winter temperature?

Baie des Chaleurs Aquaculture Inc. in Carleton, Quebec has demonstrated the feasibility of land-based salmon farming in that province where lethal winter sea temperature precludes year-round culture in sea cages (Boudreau 1988). Geothermal water from brackish and freshwater wells is supplied to large steel tanks holding 466 m^3 of water with capacity of 4000 market size salmon. The annual thermal range is from 2.5-15.0°C. Ground water is used exclusively in winter and additional seawater is pumped to the tanks at other seasons. Another land-based salmonid farm, Marine Harvesting Ltd., has recently begun rearing rainbow trout in Georgetown, Prince Edward Island. Anderson (1988) makes a strong case for development of land-based salmon farms because these offer protection from storms, more scope for environmental control and better community acceptance. Provision of water with an acceptable annual thermal regime, when possible, would further increase the suitability of land-based mariculture sites.

Salmonid mariculturists in Nova Scotia, Newfoundland and New Brunswick have taken advantage of thermal stratification in local areas to overwinter salmon and trout. Little Narrows Pond (Bras D'Or Lake in Cape Breton), Bay D'Espoir and Holyrood Pond in southern Newfoundland and Kennebecasis Bay, New Brunswick (Fig. 4, 6), have water of suitable temperature overlain by fresh or brackish water which is ice-covered in winter. Salmonids are held overwinter in submerged cages or in onshore tanks supplied with water pumped from these bays or ponds. Holding salmonids in submerged cages without access to the air-water interface causes buoyancy problems in these fishes which must swallow air to maintain swimbladder volume (Mikheyev et al. 1970; Eriksson 1983). This problem can be overcome by placing an air-filled dome in the submerged cage or by bubbling air through the cage (Saunders 1988). Submerged cage technology may be useful where suitable environmental conditions exist and as a way of providing protection from wave-swept surface water.

Seasonal production is possible in most areas where there is adequate protection from wind and heavy seas and where other environmental conditions are suitable. However, this strategy is probably not feasible in view of the high cost of smolts and the relatively small size attainable from spring to early winter. Rainbow trout may be more appropriate for this strategy because the seed stock are more easily produced and less expensive. Salmon farmers in Iceland, where winter temperature precludes overwintering in most coastal areas, use "super smolts" of ca. 400 g (Isaksson 1985) which can reach 1.5-2.0 kg in sea cages between May and October.

Photostimulation of growth may be a useful strategy to produce salmon of market size before onset of lethal conditions. Provision of extended daylength in autumn-early winter enhances juvenile growth and an increase in the incidence of 1+year-old smolts (Saunders et al. 1989). This strategy is also effective during the postsmolt stage in seawater. Saunders and Harmon (1988) reported that postsmolt Atlantic salmon in the laboratory grew significantly faster in response to various extended daylength regimes between August and January than those under simulated natural daylength. There was little or no increase in maturation as grilse following photoperiod treatment. Attempts are being made to develop technology for such photostimulation of postsmolts under sea cage conditions.

Many attempts have been made to use thermal effluent from power plants as an inexpensive way of heating water for growing fish in cold climates. There is an extensive report (Anon. 1981) of an international conference on the use of thermal effluent in aquaculture. Notable examples of such effective use in Atlantic Canada are the New Brunswick Department of Natural Resources' Grand Lake salmonid rearing station using heated effluent from a coal-fired generating station, smolt rearing at Bay D'Espoir, Newfoundland using bearing cooling water from a large hydroelectric plant and a salmon hatching-rearing unit using bearing cooling water from the Mactaquac hydroelectric station on the Saint John River, New Brunswick. A Cape Breton company, Nova Aqua, has a large, land-based ongrowing plant using thermal effluent from a coal-fired generating station in Lingan.

Fletcher and his colleagues (Fletcher et al. 1988) are conducting innovative research on genetic manipulation to produce salmon with greater resistance to freezing. Some marine fishes, including the winter flounder (*Pseudopleuronectes americanus*), have genes involved in production of polypeptide antifreeze compounds (Hew and Fletcher 1985). Recombinant DNA technology is used to produce such genes from the flounder outside the host animal. The genes are inserted into recently fertilized salmon eggs. Fletcher and his colleagues have found that the genes are retained by the developing salmon and express themselves by producing antifreeze compounds (G.L. Fletcher, personal communication).

PROSPECTS FOR THE FUTURE

The future appears bright for the areas in eastern North America where salmonid mariculture has become established, i.e. southwestern New Brunswick, northeastern Maine and parts of Nova Scotia, where winter sea temperatures are acceptable. Environmental conditions favor rapid growth in spite of long winter periods with low temperature. The thermal regime, including this period of little growth, is favorable since salmon reach market size (3-5 kg) in 16-18 mo in sea cages and with lower incidence of grilse than for the same stocks in nature. Such growth rates are at least as high as the best in Norway and Scotland. Atlantic Canada and Maine enjoy a further advantage of proximity to a large market in the eastern USA and Canada.

There is also some promise for other parts of the study area where winter sea temperatures are unacceptable. Research and resulting technology have already led to significant salmonid production in these areas. Research and pilot scale operations show that salmonid production is biologically feasible using various technologies described earlier. Application of such technology will depend on the economic feasibility, to be determined for each set of technologies and the locations where they are being tested. The infrastructure for a successful, extensive salmonid mariculture industry is in place. The status of broodstock development, smolt supply, production of cages and nets, fish feeds, processing and marketing, disease diagnoses and fish health services, and research and technology development is well advanced owing to the long history of salmonid research in the area and a solid base for production developed since the industry began in 1978.

REFERENCES

Anderson, J. M. 1988. Land-based salmon farms. Bull. Aquacult. Assoc. Can. 88-3: 14-17.

Anon. 1981. Proceedings of the World Symposium of Aquaculture in Heated Effluents and Recirculation Systems, Stavangek, 28-30 May, 1980. Vol. I and II.

Boudreau, W. 1988. Saumum. The story of Canada's first land-based salmon farm. Bull. Aquacult. Assoc. Can. 88-3: 19-25.

Eriksson, T. 1983. Growth, sexual maturation and survival of net pen-reared Baltic salmon, *Salmo salar* L., in the Bothnian Sea, with special reference to wintering conditions. Aquilo Ser Zoologica 22: 109-113.

Fletcher, G. L., M. H. Kao, and J. B. Dempson. 1988. Lethal freezing temperatures of Arctic char and other salmonids in the presence of ice. Aquaculture 71: 369-378.

Fletcher, G. L., M. A. Shears, and M. J. King. 1988. Evidence for antifreeze protein gene transfer in Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 45: 352-357.

Hew, C. L., and G. L. Fletcher. 1985. Biochemical adaptation to the freezing environment - structure, biosynthesis and regulation of fish antifreeze polypeptides, p. 553-563. In R. Gilles [ed.] Circulation, respiration and metabolism. Springer-Verlag, Berlin.

Hogans, W. E., and D. J. Trudeau. 1989. *Caligus elongatus* (Copepoda:Caligoidea) from Atlantic salmon (*Salmo salar* L.) cultured in marine waters of the lower Bay of Fundy. Can. J. Zool. 67: 1080-1082.

Isaksson, A. 1985. The production of one-year smolts and prospects of producing zero-smolts of Atlantic salmon in Iceland using geothermal resources. Aquaculture 45: 305-319.

Lauzier, L. M., and J. H. Hull. 1969. Coastal station data temperatures along the Canadian Atlantic coast 1921-1969. Fish. Res. Board Can. Tech. Rep. 150: 5 p. + appendices.

Mikheyev, P. V., Y. V. Meysner, and V. P. Mikheyev. 1970. The importance of contact with the air in the life of the rainbow trout. J. Ichthyol. 10: 691-693.

Reddin, D. G. 1985. Atlantic salmon (*Salmo salar*) on and east of the Grand Bank. J. Northw. Atl. Fish. Sci. 6: 157-164.

Saunders, R. L. 1987. Winterkill! The reality of lethal winter sea temperatures in east coast salmon farming. Bull. Aquacul. Assoc. Can. 87-1: 36-40.

Saunders, R. L. 1988. Algal catastrophe in Norway. World Aquacul. 19: 11-12.

Saunders, R. L. 1989. Salmonid mariculture in Atlantic Canada and Maine, U.S.A. In A. D. Boghen [ed.] Cold-water aquaculture in Atlantic Canada. Can. Inst. Res. Regional Develop., Moncton, N.B.

Saunders, R. L., and P. R. Harmon. 1988. Extended daylength increases postsmolt growth of Atlantic salmon. World Aquacul. 19: 72-73.

Saunders, R. L., E. B. Henderson, B. D. Glebe, and E. J. Loudenslager. 1983. Evidence of a major environmental component in determination of the grilse:larger salmon ratio in Atlantic salmon (*Salmo salar*). Aquaculture 33: 107-118.

Saunders, R. L., B. C. Muise, and E. B. Henderson. 1975. Mortality of salmonids cultured at low temperature in sea water. Aquaculture 5: 243-252.

Saunders, R. L., J. L. Specker, and M. P. Komourdjian. 1989. Effects of photoperiod on growth and smolting in juvenile Atlantic salmon (*Salmo salar*). Aquaculture 82: 103-117.

Sutterlin, A. M., E. B. Henderson, S. P. Merrill, R. L. Saunders, and A. A. MacKay. 1981. Salmon rearing trials at Deer Island, New Brunswick, with some projections on economic viability. Can. Tech. Rep. Fish. Aquat. Sci. 1011: 28 p.

THE PRESENT STATUS AND FUTURE PROSPECTS OF SALMON FARMING IN BRITISH COLUMBIA

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ABSTRACT

Spence, J. A., D. Eagan and M. Evans. 1991. The present status and future prospects of salmon farming in British Columbia, p. 37-50. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

The development of the B.C. farming industry since 1973 is outlined. As of January 1989, 207 salmon farming leases and licenses had been issued in B.C. There are about 105 operating companies, of which about 60 have commenced the sale of chinook, coho, Atlantic salmon and rainbow trout. Production is expected to increase to 14,500 metric tonnes (MT) in 1989. The production and holding capacity is concentrated; 7% of farms were responsible for 44% of production in 1988.

The distribution of marine and freshwater operations is shifting from the Sunshine Coast to Vancouver Island. The total planned holding capacity of 44.3 million m^3 by licensed farms is approximately 57,800 MT. Seasonal distribution of production is timed so as not to coincide with the wild fishery, but is subject to fish maturation patterns. Important developments in broodstock supply and sources have reduced the constraints of egg availability. The industry, with the help of university and government research, is making progress in dealing with the major disease problems of vibriosis and bacterial kidney disease. An examination of the growth patterns and production cycles of chinook and Atlantic salmon leads to the prediction that these will become the dominant farmed species in B.C. Currently, harvesting, processing and selling are in a developmental stage. Different market channels are evolving in response to the location of farms and their relation to processing facilities and competition for supplies by major processors.

RÉSUMÉ

Spence, J. A., D. Eagan and M. Evans. 1991. The present status and future prospects of salmon farming in British Columbia, p. 37-50. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

On décrit l'évolution de l'industrie piscicole en C.-B. depuis 1973. En janvier 1989, on dénombrait 207 baux et permis de pisciculture dans la province. On recense environ 105 entreprises piscicoles en activité, dont une soixantaine ont commencé à venfre du saumon royal, du saumon coho, du saumon de l'Atlantique et de la truite arc-en-ciel. On s'attend à ce que la production atteigne 14 500 tonnes métriques en 1989. La capacité de production et d'utilisation est concentrée, puisque 7% des piscicultures fournissaient 44% de la production en 1988.

La pisciculture en eau de mer et en eau douce tend à se déplacer de la côte Sunshine à l'île de Vancouver. On chiffre à environ 57 800 tonnes métriques la capacité prévue des 44,3 millions de mètres cubes offerts par les établissements piscicoles agrées. La distribution saisonnière de la production est planifiée de manière à ne pas coïncider avec la pêche du saumon sauvage, mais dépend cependant du processus de maturation du poisson. Des améliorations importantes en ce qui a trait aux sources de production et de fourniture de géniteurs ont permis de réduire les obstacles posés par l'approvisionnement en oeufs. Avec l'aide des scientifiques universitaires et gouvernementaux, l'industrie réalise des progrès dans le traitement des principales maladies comme la vibriose des poissons et la maladie rénale bactérienne. Un examen du processus de croissance et des cycles de production du saumon royal et du saumon de l'Atlantique permet de prédire que ces espèces domineront la pisciculture en Colombie-Britannique. À l'heure actuelle, la récolte, la transformation et la vente sont en voie de développement. Différentes filières commerciales se développent en fonction de l'emplacement des piscicultures et de leur relation avec les installations de transformation ainsi que de la concurrence pour le produit exercée par les grands transformateurs.

INTRODUCTION

This paper provides an overview of the salmon farming industry in British Columbia as of January, 1989. The historical development of the industry is first summarized. Descriptions of industry organization, production and market trends follow. Finally, constraints to growth are discussed.

Commercial salmon farming ventures in B.C. commenced in the early 1970's, with efforts aimed at pan-sized coho and some chinook production. Many of these ventures failed after an initial round of financing when they experienced substantial mortalities and a range of technical difficulties. The reasons were complex, but were related to inadequate broodstock, poor site selection, poor husbandry techniques, poor diets, and a lack of understanding of major diseases such as bacterial kidney disease, furunculosis and vibriosis. In short, they experienced the full range of problems normally associated with bringing a new species into cultivation. However, these efforts produced a generation of fish farming enthusiasts who have played an important role in the subsequent expansion of commercial salmon farming in B.C.

The current expansion of production which began in 1984 was fuelled by the successes of the European salmon farming industry in the early 1980's. The awareness of a large developing market for fresh farmed salmon in the U.S.A. stimulated investment and renewed efforts at salmon farming in B.C. In the winter of 1979-80 the first significant exports of European farmed salmon to America commenced. These exports have grown from about 500 MT in 1988 and are currently running at about 2000 MT/mo.

Again, efforts were concentrated on chinook and coho, partly because these are the native species most suited to farming and partly because they have high market prices. The restrictive attitude of the federal Department of Fisheries and Oceans towards importations of Atlantic salmon eggs, due to concerns about disease transference and the introduction of a non-native species, also forced many companies to work with locally available stocks.

INDUSTRY OVERVIEW

EXPANSION OF FARM SITES

Figure 1 shows the growth in the number of production tenures (includes both leases and licenses) issued by the Province of British Columbia since 1976. These have grown from five issued in 1976-77 to 207 as of January 1989. This rapid growth in tenures commenced in 1984. As of December 1988, 232 tenure applications were pending. However, only 68 investigative permits had been issued, suggesting that the demand for new licenses has begun to ease off.

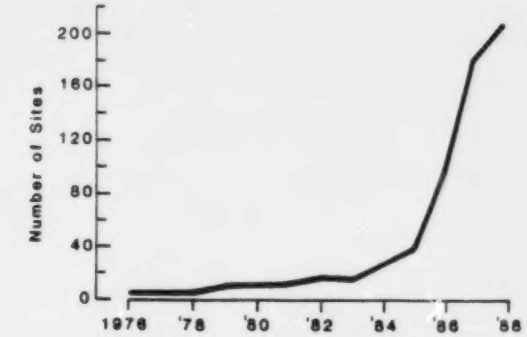

Fig. 1. Number of salmon farm sites in B.C. (source: B.C. Ministry of Agriculture and Fisheries).

The current status of the industry is outlined in Table 1. An estimated 105 companies or groups currently hold the 207 production tenures for salmon farming in B.C. Only about 60 companies are expected to produce salmon for market in 1989. In 1988, total production of farmed salmon in B.C. amounted to approximately 6040 MT. Production is expected to increase to 14,500 MT in 1989.

CURRENT FARM CAPACITY

Given the number of net pens that are proposed in each license application granted by the provincial government and, assuming a stocking density of 8 kg/m^3 per pen, one can estimate the present total installed net pen holding capacity of the B.C. industry to be about 7.2 million m^3, or 57,800 MT. This holding capacity is sufficient to provide for an annual production of about 38,500 MT, and is well in

Table 1. B.C. salmon farming industry key statistics as of January 1989 (source: B.C. Ministry of Agriculture and Fisheries, unpublished data).

No. of leases issued	207
Operating companies	105
Producing companies	60
New companies not producing	82
Investigative permits	68
Pending applications	232
Estimated total production in 1989 (MT)	14,500
Total planned capacity in existing licenses (m^3)	7.2 million

excess of the estimated 1989 production of 14,500 MT. It is indicative of the early start-up phase that many companies have not yet progressed beyond.

STRUCTURAL ASPECTS

The industry structure is outlined in Table 2. According to B.C. Salmon Farmers' Association data, 60 companies will produce salmon for sale in 1989. Four companies are expected to have 1989 production levels in excess of 1000 MT. These four companies, or 7% of the total, will produce about 44% of the total expected production. If contract rearing and other business arrangements between the larger companies and smaller production units are considered, the anticipated volume of production in 1989 controlled by the larger companies could be as much as 65% of the total.

According to information provided in tenure applications, 10 companies have a total holding capacity of over 1000 MT. As expected, the distribution of holding capacity by company size is almost identical to the distribution of production by company size.

A comparison of the industrial organization of the B.C. salmon farming industry in 1986 to that in 1988 indicates that the concentration in production has not changed much since. Therefore, it is expected that more than 60% of all production in the early 1990's will come from about 12% of the farms. The concentration of production is similar to the concentration in Scotland and Chile.

GEOGRAPHICAL DISTRIBUTION OF FARMS

The distribution of marine and freshwater rearing sites in British Columbia is shown in Fig. 2. Figure 3 shows the geographical distribution of companies and their holding capacity in B.C.

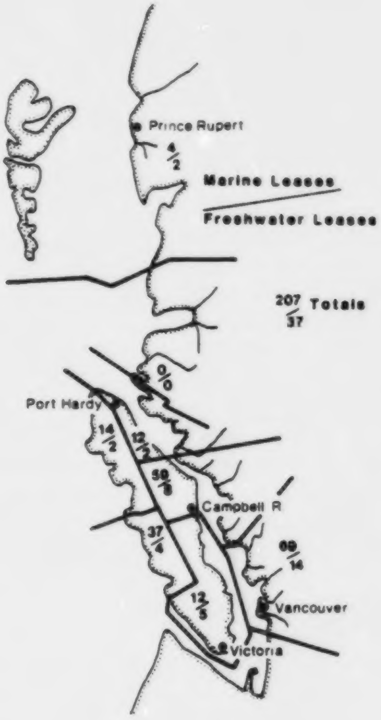

Fig. 2. Distribution of marine and freshwater leases in B.C.

Table 2. Estimated distribution of production by company size in 1989 (source: B.C. Salmon Farmers' Assoc. and independent company data).

Production level (MT)	No. of companies	% of total	1989 forecasted froduction (MT)	% of total
>1000	4	7	6,400	44
500-1000	3	5	2,300	16
300-500	7	12	2,900	20
200-300	7	12	1,450	10
100-200	11	19	1,160	8
<100	27	45	290	2
Totals	59	100	14,500	100

as of January 1989. The first region to experience extensive development was the Sunshine Coast because of its close proximity to Vancouver. From Fig. 3, it is apparent that the Sunshine Coast region still retains the greatest number of leases, companies and total licensed holding capacity. However, in the last 3 yr, there has been substantial expansion of leases in the Campbell River area, in the northeast of Vancouver Island and on the west side of Vancouver Island. The Island regions are reasonably well serviced, experience fewer conflicts between salmon farming and other coastal user groups and have more suitable environmental regimes for salmon farming. The environmental advantages include lower summer surface water temperatures, higher winter surface temperatures, a lower incidence of algal blooms, fewer salinity fluctuations, better water exchange and, in general, more stable oceanic regimes.

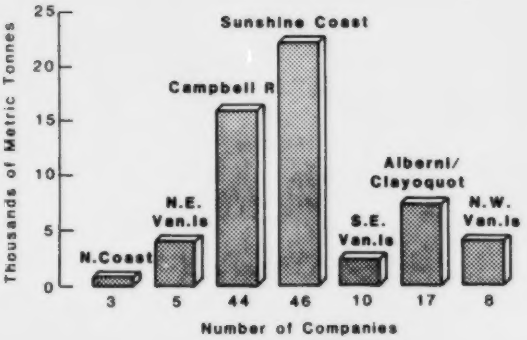

Fig. 3. Regional distribution of salmonid growout capacity in B.C. (source: B.C. Ministry of Agriculture and Fisheries, unpublished data).

If Vancouver Island is considered as a whole, it is by far the main focus of salmon farming activities. At present, Vancouver Island is the base for 134, or 65% of the total leases, which are held by 84 companies and account for 34,000 MT of holding capacity. It is expected that this shift of production towards Vancouver Island will continue in the near future.

PRODUCTION TRENDS

The increase in production of farmed salmon in B.C. from 1979 to 1989 is shown in Fig. 4. Annual production did not exceed 1000 MT until 1987. It is currently undergoing a rapid

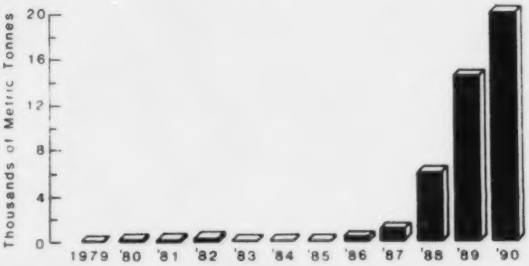

Fig. 4. B.C. farmed salmon production 1979-90 (sources: 1979-87, Department of Fisheries and Oceans; 1988-90, B.C. Salmon Farmers' Association).

expansion with 14,500 MT expected in 1989 and approximately 20,000 MT by 1990. This is substantially short of the planned business plan capacity of about 57,800 MT. At the present rate of expansion, this capacity would not be fully utilized until about 1993. However, the actual rate of utilization will depend on the availability of financing and the strength of markets.

SEASONAL PRODUCTION

The distribution of 1988 and expected 1989 production by month is shown in Fig. 5. In 1988, a 12-mo continuity of supply to world markets was achieved in B.C. for the first time.

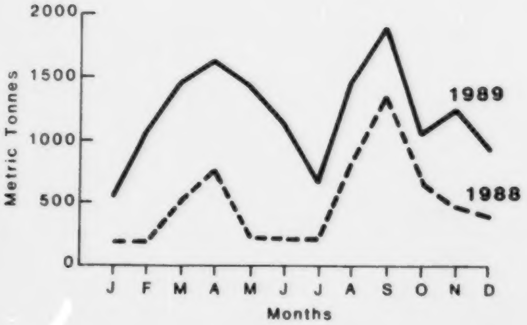

Fig. 5. Comparative monthly production of B.C. farmed salmon in 1988 and 1989 (source: B.C. Salmon Farmers' Association).

The pronounced seasonality in 1988 is related to the planning of farmed harvests around the fresh, wild fishery, the products of which are sold from early May to the end of August. Farmed production shows a peak in March and April when farms harvest out sterile coho and chinook after 22-24 mo of growth at sea. Harvesting is at a low level through the summer, with a peak in August or September. This peak is made up largely of coho and male chinook (jacks) starting to undergo sexual maturation after 14-16 mo of growth at sea. There are also increasing quantities of larger 27- to 30-mo-old chinook appearing at this time in the higher weight categories. In 1989 and in future years, this seasonality is expected to flatten out as market outlets are developed that require a consistent supply of fresh salmon year-round. However, distress selling of product by producers with cash flow problems may distort the ideal pattern and lead to imbalances between supply and demand.

SPECIES REARED

Figure 6 shows typical growth patterns of chinook salmon, coho and Atlantic salmon in net pens in B.C.

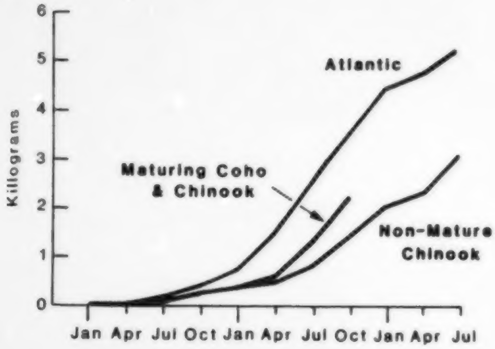

Fig. 6. Comparative salmon species growth (source: Independent Company data).

Chinook clearly have the advantage of a very compacted freshwater life and early smolting at a size of 10 g or less. Typically, eggs of this species are stripped in November. They hatch early in the year and are smolting between April-June under optimal rearing conditions. At the end of their first year, they may reach 300-500 g. By 24 mo at sea, average weights are in excess of 2 kg. In the third year at sea, they can be profitably marketed at weights up to 4 kg.

Atlantic salmon, in contrast, are 1 or 2 yr old when they smolt. Under the mild conditions of the West Coast, they grow very rapidly and are at a marketable size within 12-18 mo of going to sea.

When the main production characteristics of chinook and Atlantic salmon are examined (Table 3), the merits of these two species in B.C. production strategies become evident. It is anticipated that significant progress will be made in improving chinook growth rates, reducing jacking rates and in reducing mortalities related to bacterial kidney disease, the most prevalent disease affecting chinook. Thus, the profitability of this species could approach that of Atlantic salmon. These two species are expected to become the mainstay of B.C. salmon farming.

Table 3. Comparative production characteristics of Atlantic and chinook salmon.

	Chinook	Atlantic
Age at smolting	0+	1+ 2+
Weight at smolting	5-10 g	40-80 g
Weight at 18 months at sea	1.5-2.5 kg	3-5 kg
Cum. sex. mat. at 2 years	15-30%	<20%
Avg. stocking densities	5-10 kg/m^3	10-20 kg/m^3
Expected mortalities	20-50%	10-20%
C. convolutus	Tolerant	Sensitive

Atlantic production will be concentrated in the cooler water areas, particularly the northern end of Vancouver.

Over the last 3 yr, extremely variable results have been obtained in rearing coho from a few Georgia Strait stocks. These results included a high incidence of smolt reversion in regular fish, and a very poor growth rate and high disease susceptibility in sterilized fish. More recently, efforts with some northern stocks of coho have produced promising results when accelerated (0+) smolts are put into net pens early. These are reported to give a growth performance comparable to Atlantic salmon after 12 mo in a net pen.

EGG AND SMOLT PRODUCTION

The sources and numbers of eggs incubated in commercial hatcheries in B.C. in the fall of 1988 are shown in Table 4. In 1988, of 39 million chinook eggs, we anticipate production of about 26 million smolts.

There are three categories of hatchery and freshwater rearing sites: 1) surface water sites, usually fed by coastal streams with very seasonal flow patterns and extreme temperature variations; 2) groundwater hatchery sites, located mainly on the large aquifers on Vancouver Island; and 3) freshwater lake sites, used for the net pen rearing of fry, three of which are in operation in B.C.

The number of surface water stream sources available for commercial hatchery development in B.C. is limited. Most surface streams sustain wild runs of Pacific salmon and it is difficult or impossible to obtain permission for development on these water sources.

Out of an estimated 30 hatcheries, only about six are supplied entirely with surface water. Three are run off a combination of surface and ground water and 21 are dependent on constant temperature ground water. About 70% of the production in 1988 came from groundwater supplied hatcheries.

Constant temperature ground water has several advantages, particularly for the production of 0+ chinook smolts. It is disease-free and the higher temperatures (6-12°C) allow more rapid incubation than in surface water. Rapid growth in the fry results in an early chinook smolt which is transported to the net pens in April or May.

With Atlantic and coho salmon, however, a constant temperature regime may inhibit proper smolting, resulting in a high incidence of smolt reversion and mortality after transfer to sea. The low number of coho eggs incubated reflects the poor results that have been obtained in rearing coho, related to smolt reversion, susceptibility to algal blooms and early maturation. In contrast, prior to 1988, the low number of Atlantic eggs reflects only the low number of local broodstock due to limits placed by the federal government on Atlantic egg imports. The number of Atlantic eggs incubated also increased dramatically in 1988.

In the early stages of development of the industry, hatcheries and farms were entirely dependent on eggs from wild fish or hatchery released wild stocks. The performance of these wild stocks was variable and ongoing mortalities were very high, frequently in excess of 50%.

Table 4. Eggs incubated in commercial hatcheries in B.C., 1988-89 (millions) (source: BCSFA and industry sources).

Domestic chinook eggs	36.0
Wild strain chinook eggs	3.0
Domestic coho eggs	2.0
Wild coho eggs	0.3
Atlantic eggs	3.0
Total eggs	44.3 million

Over the last 3 yr, there has been a major shift towards the development of captive broodstocks. By 1986, about 50% of all the chinook eggs utilized by the industry were reared from on-farm broodstock. In the fall of 1988, more than 90% of all the eggs laid down in hatcheries were derived from farm-reared parents (Table 4). In addition, the wild strain chinook eggs laid down had commercial potential.

The principal factors permitting this shift to use of domesticated stocks have been the recent improvements in Pacific salmon broodstock diets and in the management of broodstock. As a result, the average egg survival during hatchery incubation of chinook has risen from less than 50% last year to 75-80% in the winter of 1988-89.

The larger integrated farms all select and hold their own chinook broodstock populations from the better performing production fish. Most of these fish are derived from a few southern stocks, in particular Robertson Creek, Big Qualicum, and Quinsam River stocks on Vancouver Island.

The industry recognizes that, following intensive selection of wild stocks that is now occurring on farms, significant genetic gains will only be made through systematic line breeding programs at the family level. These programs are now being established by several of the larger fish farming operators. Along with this industry initiative, there are plans for associated government-financed genetic research and monitoring of performance of different strains. A broodstock development program is also under way with government funding to compare the performance of about 20 different strains of chinook. This program is also comparing the performance of certain families within these strains and it is expected to get information on the heritability of commercially relevant characteristics such as growth rate, the incidence of precocious maturation (jacking), the age at sexual maturity, flesh color and disease resistance.

Progress is also being made in the selection of domestic coho broodstock. In particular, good results are being reported in the performance of descendants of some northern strains of coho. These fish are reared as accelerated coho smolts and give positive results with early seawater entry.

PROCESSING

The development of an appropriate infrastructure to allow the efficient harvesting, transport, processing and sale of large volumes while retaining high product quality has become essential in salmon farming. In B.C., the developing salmon farming industry has made extensive use of the existing infrastructure of the wild salmon industry. However, custom-designed systems dedicated to the exclusive handling of farmed salmon are being found increasingly in the major salmon farming regions.

At the present time, about 10 plants set up to process wild salmon and other seafood are regularly processing farmed salmon. This makes good use of the excess processing capacity in these plants which has been estimated at about 10,000 MT during the November-April off season of the wild fishery (DPA 1987). In addition, at least seven custom-designed plants for farmed salmon have been set up - four on the Sunshine Coast and three in the Campbell River area.

These plants have an estimated average annual capacity of about 1500 MT/yr. Thus, the present available capacity for processing fresh farmed salmon is approximately 20,000 MT/yr. As the industry expands, additional capacity will be required in the major producing areas.

The dispersion of the salmon farming industry along the extensive coastline of B.C. poses particular problems in the harvesting and transport of product for processing and marketing.

Several different options are presently being used, depending on the relative locations of the farm, processing plant and point of export. They can be categorized as follows:

1. Harvesting, bleeding and processing locally, followed by transport of packaged product to point of sale;
2. Harvesting and bleeding at the farm, followed by transport (by road or sea) to distant processing (usually in Vancouver) and sale;
3. Harvesting, followed by transport of live fish to distant processing, followed by sale.

The first system is used most commonly on the Sunshine Coast where there are processing plants convenient to the farms. Only a very few B.C. farms have their own processing capability.

The second and third systems are the most frequently used. Harvesting and bleeding at the farm is carried out by the most remote farms. This is the most economical system, but it results in a longer transport time to market for the slaughtered fish and therefore slightly reduces the available shelf life.

The third option is frequently used in B.C. for hauling live fish to centralized processing plants up to 100 km from the grow-out units. Here, infrastructure developed for the wild fishery is utilized. Packer boats formerly used for transporting dead salmon on ice to the canneries and freezer plants have been converted for live haul. This involves the installation of oxygenation and seawater pumping systems in their multiple holds and a vacuum pump is mounted on deck to pump fish from the pens into the hold and from the hold up to the processing plant for bleeding and slaughter. During 1989, as many as 10 such boats will be operating along the coastline.

SALES AND DISTRIBUTION

Established patterns have begun to emerge with salmon marketing. Table 5 shows the sales and distribution channels for B.C. production in 1988. It can be seen that established Canadian processing and broker groups of the wild salmon industry have taken the lion's share of production; however, the diversity of the first sales outlets is notable.

Producers can be expected to continue to test the various possible distribution channels to determine the best farm gate price. At least four contract rearing arrangements have recently emerged in the industry with large marketing groups or venture capital sources providing the funds in return for sales contracts. It is expected that the strength of these groups will determine the sales channels for an increasing proportion of B.C. production. It is also expected that specialist sales organizations linked to the large producing companies or cooperating groups of companies will emerge. These structures could do much to ensure that production is planned according to market demand.

PRODUCT FORMS

At the present time, most of the product is shipped from processing plants fresh, graded and gutted with head on and gills out. The vast majority of production has been sold in major centres in the U.S. and central Canada. Some frozen salmon has also begun to be sold to Japan. It is expected that increasing amounts of product will be sold in value-added forms.

COSTS OF PRODUCTION

Little economic information has been collected on the B.C. salmon farming industry at an aggregate level. As a result, few conclusions can be drawn about its cost structure.

Actual cost of production will be influenced by factors such as the scale of operations, the efficient utilization of feed, the degree of automation to reduce labor costs and the survival of stock throughout a 24-mo or

Table 5. Sales and distribution channels for B.C. farmed salmon production in 1988 (source: B.C. Salmon Farmers' Assoc.).

B.C. fish processing and sales groups	32%
Canadian brokers and exporters	33
Canadian wholesalers	10
Foreign (U.S.) based importers and wholesalers	21
Direct sales to restaurants, retailers and secondary processing	4
	100%

longer production cycle. In established farms with a good track record, the cost of production (before processing and selling costs) should be close to $5.00/kg.

In general, the present cost level of the B.C. industry appears to be relatively high but declining steadily as operations mature. There is, however, considerable scope for further reductions in costs through advances such as feed automation, improved diets, improved growth and survival of stocks and the development of more efficient management systems.

Significant progress has been made in improving performance with regard to most of these variables, in particular growth rates, food conversion ratios, mortality rates and processing costs. If this trend is continued in combination with development of more efficient production technologies, B.C. will become a very efficient producer of farmed salmon.

A cost-of-production model has recently been developed of a theoretical single-site salmon farm in B.C. producing about 250 MT/yr.

This model considers all the major components of the variable and fixed input costs of a B.C. salmon farm. Using actual cost data from operations in B.C., it can give a base case for cost of production of a small farm and can demonstrate the impact of an alteration in important parameters. The base case is shown in Table 6. The major assumptions in developing the cost profile are listed below:

- start-up capital costs are $605,000 - housing and storage are on a floating barge adjacent to a steel cage system (land costs are disregarded);
- chinook smolts at 5 g are introduced in June;
- harvesting occurs after a 17-mo grow-out period and continues until the 21st month;
- feed conversion is 1.5:1 during the first 5 mo and 1.8:1 thereafter;
- cumulative mortalities are 30%;
- smolts are $0.67 each; feed costs are $1.34/kg;
- processing and selling are conducted by a seafood processor - processing costs include live haul transport;
- moderate debt levels are assumed for working capital and start-up financing.

This base case describes a relatively efficient farm. Market prices for 2- to 3-kg chinook in the fall of 1988 would have allowed for a profit margin of about 30%. However, many developing farms likely have a C.O.P. that is higher due to higher levels of mortality, interest burden and poor husbandry. Therefore, profit margins are often lower for new farms.

There is substantial scope to reduce costs of production in the B.C. salmon farming industry. As indicators, the impact on C.O.P. of improving feed conversion by 10%, increasing growth by 25% and reducing mortality by 50% are shown in the three scenarios in Table 7. The analysis suggests the most important production factors are growth rates and survival rates.

Table 6. Cost structure in the B.C. salmon farming industry (source: DPA Group Inc., 1989) - a base case.

	Cost/kg*	%
Variable costs:		
Smolt	$0.31	4
Feed	3.06	44
Processing	1.25	18
Stock insurance	0.16	2
Interest on working capital	0.30	4
Selling	0.87	13
	$5.95	85%
Fixed costs:		
Production**	$0.54	8
Administration	0.15	2
Depreciation	0.29	4
Financing	0.10	1
	$1.08	15
TOTAL COSTS	$7.03	100%

*Costs are on a dressed, head-on basis.
**Labor costs are included in fixed costs and are $0.42/kg.

Table 7. Impact of alternative scenarios on cost structure (source: DPA Group Inc., 1989).

	Unit costs per kilogram			
	Base case	10% improvement in FCR	25% increase in growth rate	50% reduction in mortalities
Variable costs	$5.95	$5.73	$5.77	$5.61
Fixed costs	1.08	1.08	0.95	0.90
Total costs	$7.03	$6.81	$6.72	$6.51
% change in unit cost from base case		(3%)	(4%)	(7%)
% change in net income from base case		+9%	+32%	+40%

(Regarding the latter, the scenarios assume losses occur more or less evenly throughout the cycle, such as those resulting from the chronic effects of bacterial kidney disease.)

CONSTRAINTS TO GROWTH

The major factors limiting expansion in B.C. will be related to the demonstration of profitability in world markets, where prices cannot be expected to increase. Factors that have limited B.C. production in the past, such as the lack of suitable chinook broodstock and good hatchery production techniques, are no longer likely to be limiting. No constraints on the availability of good quality chinook eggs and smolts are anticipated. In fact, the B.C. industry in 1 yr has moved from a severe chinook smolt shortage in the spring of 1988 to an expected surplus, or at least a state of fully sufficient supply in the spring of 1989. It is also expected that the supply of Atlantic salmon eggs and smolts from local broodstocks will increase substantially within the next 2 yr.

Other major factors that affect the number of new tenures being developed and the ongoing expansion of the industry are financing, site scarcity, disease and other production constraints.

Capital available for investment in salmon farming is limited, particularly for farming of Pacific species which are still perceived to be risky and bring a lower return on investment than the farming of Atlantic salmon.

A scarcity of new sites with good potential that have access to roads, harbors, processing capacity and other services, and are within reasonable distance of the various amenities of civilization such as housing, schools and hospitals is already evident. Also, some already licensed sites may never be developed commercially owing to poor results in the early years of operation and their unsuitability for large-scale operations.

Increasing rigor in the evaluation of site applications by different government agencies and increasing conflicts with other coastal user groups such as recreational interests, the traditional fisheries and environmental interests are taking place. The significance of these constraints, however, does vary greatly from region to region.

As elsewhere, vibriosis, caused by several species of *Vibrio* bacteria, has been a serious problem, especially in fish in the first year at sea. However, it is now kept under control by improved management, backed up by vaccination of smolts before they go to sea and antibiotic therapy. Mortalities from this source generally should not exceed 15% in the first year at sea.

The dominant bacterial problem has been bacterial kidney disease (BKD). In the last 2 yr, however, substantial improvements have been made and average mortalities from BKD over a 2-yr sea cycle have been reduced from levels sometimes in excess of 50% to 20-30% or lower.

The following factors help explain the major reduction in BKD mortalities:

- improvements in husbandry practices and reduction of the stress levels to which fish are exposed;
- the increased use of eggs from domesticated broodstock that are screened for BKD;
- the development of effective prophylactic therapies with oxytetracycline and other antibiotics and prophylactic treatment of broodstock prior to stripping.

Substantial research efforts are directed towards combatting this disease. These include studies on non-salmonid fish that may act as disease reservoirs adjacent to farms, investigation of the clearance rate of BKD bacteria from seawater by mussels, improved diagnostic procedures, the in vitro testing of new antibiotics and studies aimed at the development of a new vaccine.

There are currently at least eight private sector veterinarians and four diagnostic laboratories serving the industry. Recently, a reference diagnostic laboratory within the federal Department of Fisheries and Oceans has been proposed.

With the increasing numbers of fish being held and the increasing attention to diagnostics, several disease conditions new to B.C. have recently been identified. These include:

1) a toxopathic liver disease - this appears to result from some environmental waterborne toxin and may be related to chronic exposure to certain toxic algae;

2) a microsporidian infection (*Loma salmonae*) which has been associated with mortalities in older chinook salmon;

3) an eye tapeworm (*Gilquinia salmonae*) which infects the eye of chinook as a second intermediate host after transmission from a crustacean first intermediate host;

4) an anaemia of pen-reared chinook - this has been associated with mortality in 2-yr-old chinook at a few sites.

Investigations into these problems are being carried out by federal Department of Fisheries and Oceans scientists and university-based researchers.

The more sheltered and warmed parts of the B.C. coast have experienced frequent algal blooms. Some of these have caused stock losses. The two most common species that have been implicated in problems are *Chaetoceros convolutus* and a dinoflagellate *Heterosigma akashiwo*.

C. convolutus blooms frequently in the spring and fall throughout the lower Strait of Georgia. This species is characterized by long spines which damage gill tissues and cause severe haemorrhage. Atlantic salmon, rainbow trout and coho are the most sensitive species, with losses starting when cell counts are very low (about 400 cells/L). Chinook are more resistant to damage by *C. convolutus* and farms in the Strait of Georgia have learned to manage around the problem by concentrating on chinook production, holding fish in net pens up to 15 m deep and ceasing feeding during blooms.

Predators, in particular harbor seals, otters and dogfish, have caused losses of fish in some areas. Various control measures are deployed but frequent surveillance and use of string nets are the main deterrent.

SUMMARY

After a long troubled development phase lasting about 12 yr, the B.C. salmon farming industry has undergone rapid expansion in the last 4 yr. This is reflected in the large increases in the number of licensed sites in operation and, over the last 2 yr, a significant increase in the annual production of farmed chinook and coho. This growth was encouraged by the European success, and the awareness of the large American market.

At present, about four companies have annual production in excess of 1000 MT/yr. The remaining production will be split between more than 50 companies. There is a trend towards the formation of large production and marketing groups.

Substantial progress has been made in improvements in the rearing of chinook salmon, and it is expected that in future, B.C. production will be comprised mainly of chinook, while Atlantic salmon production will become increasingly important from 1990 onwards. For the foreseeable future, coho will play a minor seasonal role in B.C. production.

The rate of future expansion will be determined largely by the profitability of the industry. At the moment, profitability has not been clearly demonstrated by many companies. This and inherent financial weaknesses, in particular a high debt burden in many companies, have retarded the entry of new capital into the industry. The achievement of satisfactory profitability will also depend on progress in reducing the actual cost of production of the major species and on the maintenance of high prices in world markets.

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REFERENCES

B.C. Ministry of Agriculture and Fisheries. 1987. British Columbia Aquaculture Industry Development Strategy. 146 p.

B.C. Ministry of Agriculture and Fisheries. 1987. British Columbia Fish Aquaculture Statistics 1986. Aquacult. Info. Bull. 23: 12 p.

B.C. Salmon Farmers' Assoc. 1987. Summary of Workshop Proceedings Harvesting to Processing Procedures for Farmed Salmon. 16 p.

Deegan, R., G. Carne, and J. Truscott. 1988. 1987 salmon farm survey final report. Ministry of Agriculture and Fisheries, Province of British Columbia.

Department of Fisheries and Oceans, April, 1988. Map of Locations of Aquaculture Facilities.

DPA Group Inc. 1986. Industrial Organization of the B.C. Salmon Aquaculture Industry. Dept. of Fisheries and Oceans.

DPA Group Inc. 1989. Aquaserve 2:1, 4 p.

Kennedy, E., and S. Schenck. 1988. Marine live transportation. Proceedings of Aquaculture International, Vancouver, Sept. 6-9, 1988.

Lee, B. 1988. B.C. salmon farming industry costs and returns. Univ. B.C., M.Sc. Thesis.

SALMON FARMING IN CHILE

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INTRODUCTION

There are strong geographical similarities existing between the Pacific Northwest area, from Oregon to Alaska, and the Pacific Southwest, from Puerto Montt to Cape Horn. Such similarities are not restricted to the geography, but they also exist with topography, environment and latitude. It is possible that this situation was considered by those wise and visionary people when they decided to undertake the task of introducing salmonids in that part of the Southern Hemisphere. As a result of these introductions, trout has enjoyed, since early in the century, an unquestionable place in most of the uphill rivers of the central zone, and most freshwater courses in the southern part of Chile.

The introduction of salmon (*Oncorhynchus* spp.) to Chile was due to the interest of the United States in introducing these species to other parts of the world in the decades of the 1920's and 1930's. In that period, Chile received 20,000 chinook eggs, 314,000 sockeye and 225,000 coho. There is no information about the success of these introductions.

Toward the end of the 1960's and beginning of the 1970's, a new program was initiated with the arrival of 3,614,000 eggs of coho and chinook. Technical, political and social problems interrupted the program and it failed.

The first systematic introductions started in the early 1970's due to the desire of Japan to operate in the austral region in order to utilize the abundant krill found there as salmon food. This project began in 1972 and still continues. It has become one of the most extended efforts to introduce salmon into Chile. The results up to date are not significant in terms of the amount of salmon returning, but it is important to consider the improvement of the technical and scientific capacity developed in the country by means of training, research and counterpart participation with Japanese experts. Added to this are the expensive facilities which have been built for this ongoing work.

Toward the end of the 1970's, a North American company, Union Carbide, started ocean farming operations for profit in southern Chile, with coho and chinook salmon. The first chinook returns were detected in 1979, and they have continued with increasing rates of return, up to 4% per year for some stocks. Union Carbide installations were sold to Dom-Sea Farms from Seattle, who sold later to Salmones Antártica, a Chilean company which extended its ocean ranching operation to Aysén and Puerto Natales, located near Punta Arenas and the Magellan Strait.

Due to the success shown by Salmones Antártica, there is a growing interest among private companies to develop ocean ranching projects in the Magellan area. The large dependency of Chile upon foreign import of eggs for aquaculture makes this type of culture very attractive and of great importance. However, the bulk of the Chilian salmon industry is based on cage and pond culture, raising mainly coho (*Oncorhynchus kisutch*).

DEVELOPMENT OF SALMON CULTURE

The growth of this industry has been quite spectacular. It started in 1979 with the operation of two farms which produced 70 tonnes (MT) in 1979, establishing a landmark in the history of this activity. Production levels increased year after year with the introduction of new producers and surpassed 100 MT in 1984. In the last season (1987-88), 3500 MT were produced and projections are from 12-15,000 MT for the 1989-90 period. This explosive development of salmon culture which requires great investment and high technology, seems amazing in a developing country such as Chile, which is now among the principal producers of cultured salmon in the world.

The above situation can be explained considering the following factors:

a) At the beginning of the century, the period in which trout were introduced in Chile, the necessary knowledge of biology, biophysical environmental requirements and the behavior of this species was accumulated. Skill and experience in manipulation, prophylaxis, spawning and growing of these species in hatcheries which were built to produce fry for stocking in different courses of water were also established. Consequently, salmon growing was not a new task for Chile.

b) The environmental and geographical conditions of Chile, particularly in the southern region, are ideal and match the requirements of salmonids. This makes possible intensive cultivation of salmonids and is promising for the future development of ocean ranching.

c) The increasing professional capacity among graduates of institutes and universities in ocean-related sciences is evident. The growing spirit of enterprise among Chilean investigators is heightened by the favorable policies of the Supreme Government which encourage export activities.

d) Labor costs are low and there is an abundance of raw material, for example, fish meal. The popular desire for a greater variety in the human diet has markedly increased the demand for salmon in Chile and abroad.

e) The reversed seasons between the northern and southern hemisphere allow access to major markets with premium products in times of low availability of fresh salmon.

CURRENT STATUS

PRODUCTION

Table 1 shows the increasing level of national salmon production which, as mentioned above, reached 3500 MT this year. This level can be clearly explained given the data in Table 2 and Fig. 1, showing the chronological development of the permits for new farms which totalled 279 in 1988. From the same figure, we can see that very rapid growth begins in 1985. It is clear that the increases in production correspond to the increases in farm number beginning in 1985, and that projections for increasing future production seem justified based on recent trends in the numbers of farms being started (Table 3).

SECTOR CHARACTERISTICS

Table 3 shows the distribution of production from all sources. Seventy-nine companies supply 60.3% of the total production.

Table 1. Salmon production.

Year	MT
1981	70
1982	80
1983	94
1984	104
1985-86	1,200
1986-87	1,750
1987-88	3,500

Source: Undersecretary of Fisheries.

Table 2. Licensed farms per year.

Year	Number	%
1979	4	1.4
1980	2	0.7
1981	2	0.7
1982	8	2.8
1983	5	1.8
1984	7	2.5
1985	12	4.3
1986	29	10.4
1987	62	22.2
1988	48	53.1
TOTAL	279	100.0

Source: Undersecretary of Fisheries.

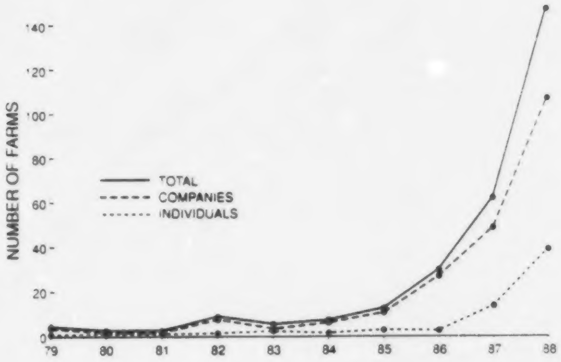

Fig. 1. Total licenced farms (1979-1988).

Table 3. Classification of salmon producer.

Classification	Number	%	Farms	%
Companies	79	60.3	203	72.8
Individuals	43	32.8	63	22.6
Education Institutions	3(4)	2.3	6	2.1
City councils	5	3.8	5	1.8
Estate	1	0.7	2	0.7
TOTAL	131	100.0	279	100.0

Source: Undersecretary of Fisheries.

Table 4. Production range (MT) of Chilean producers.

Production range (MT)	Producers	%
0- 50	34	26.0
51- 100	36	27.5
101- 300	44	33.5
300- 500	10	7.6
501-1000	5	3.8
1000	2	1.5
Total	131	100.0

Source: Undersecretary of Fisheries.

Thirty-two percent comes from 43 individual agents, while only 6.5% comes from educational establishments, state and city councils.

It is important to note that companies own 72% of the total number of farms; individuals own and operate 22.6%; educational institutions, states and municipal centers operate only 4.6%.

In relation to the estimated production capacity of the companies (Table 4), it can be observed that the major percentage of companies (33.5%) have a capacity of between 100-300 MT/yr, while only 1.5% of the farms produce 1000 or more MT/yr.

REGIONAL DISTRIBUTION

Without doubt, the geographical location of farm sites reflects the development of services such as roads, power and other vital needs. Those sites which are easily accessible are fully occupied, a condition that is very evident in Chiloé, 10th Region, which contains 86% of the country's allocated farm sites. The official standard for minimum distances between cages has reduced the possible number of sites in any region and speculators have flooded the maritime authority with requests for allocation and use of unoccupied places in order to sell them later. The 11th and 12th Regions, with abundant sites, have not attracted much interest due to the limited power supply and lack of roads. In these areas, the population is sparse and labor is scarce, making development of salmon farming difficult; only seven farm sites have been put into production in the 11th Region and only three in the 12th. This is expected to change in the near future and Magellanes is expected to become an important area for salmon ranching ventures.

In Chile's northern regions, the number of farms is restricted by the lack of well protected sites. The units that lie between the 5th and 9th Regions are freshwater trout farms, and many of them are owned by local city councils. In Chile's 3rd Region, Caldera, there is one net-pen project that successfully farms coho.

ACTIVITIES AND SPECIES

Table 5 shows the number of farms involved in the different farming activities. Some farms are vertically integrated with production processes from incubation to harvest. In other cases, a farm may execute two or more activities in parallel or sequentially. The numbers demonstrate that the major percentage of the farms (62%) is focused on grow-out and only 2.5% are involved in ocean ranching.

Although the farming industry has a marked preference for coho salmon, other species are also being cultivated. Figure 2 shows egg imports from 1979-88. Until 1986, coho salmon eggs constituted the principal species imported. From 1987, there was a significant increase in the import of Atlantic salmon eggs, which became an important import that year. This increase in Atlantic salmon farming is due in part to the activities of three foreign investors, two Norwegian and one Scottish, who are farming this species. A small but significant change of the national producers which are combining the farming of both species is also apparent.

Table 5. Farms distribution by activity.

Activity	Farms	%
Incubation	65	23.2
Smolt production	34	12.2
Growth	173	62.0
Releasing	7	2.5
Total	279	99.9

Source: Undersecretary of Fisheries.

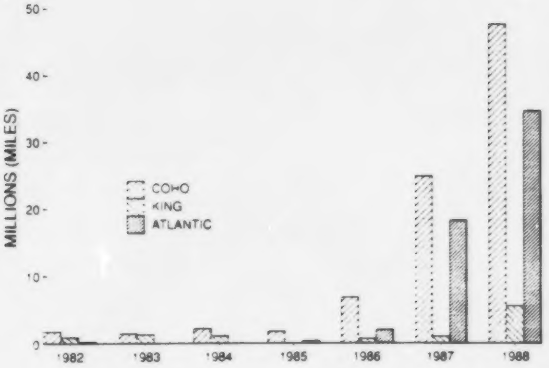

Fig. 2. Salmon egg imports (authorized between (1982-88).

PERSONNEL AND INFRASTRUCTURE

The rapid growth of salmon culture has required that companies quickly develop their capacities to deal with other processes associated with salmon farming.

From a survey of different farms conducted at the end of 1987, it was shown that there are laboratories and plants owned by companies providing services primarily to the company's farms, but also to other interested parties. Table 6 shows that 20 companies had their own feed plant, 28 had ice makers, 27 had cold storage units and 7 had processing plants. Eighteen farms had laboratories for water quality analysis, 21 had diagnostic capabilities and 6 could analyze feed quality. There is one laboratory for genetics research.

The quantities shown above, compared to those of a year before, demonstrate a significant increase in the available technical and scientific capacity to serve salmon farms. The increases of cold storage units and freezing capacity, as well as processing plants and labs for disease diagnosis, are particularly significant.

Considering that farming is characterized by maintaining fish in floating structures, the information shown in Table 7 on sea cage statistics is significant. There were at least 1260 cages in operation by the end of 1987 with over 800,000 m^3 total volume, and this, in theory, would produce over 6500 MT/yr.

An important benefit of salmon farming is employment. Table 8 shows the number of people directly involved with farming; the estimate, although conservative, is 1145 people directly employed in the industry. This number increases significantly during the harvest season from November to April. Indirectly, employment is generated by the activities related to the farming process. Gutting, packing, transport, trading, feed milling, building of net pens and tanks, net making, transport of eggs, fry and smolts, and pathology services also contribute to the demand for increased labor. Although we cannot estimate the number of jobs these activities provide, it is evident that they contribute

Table 6. Existing backup facilities.

Laboratories	No. of units	Plants	No. of units
Water analysis	18	Feed mill	20
Feed analysis	6	Ice making	28
Fish health	21	Colo storage	27
Fish genetics	1	Fish packing	7

Source: Undersecretary of Fisheries.

Table 7. Industry production capacity, 1977 - existing number and sizes of cages.

Size range (m)	No. units	m^3	Production capacity (MT)	Density kg/m^3
(1x1) - (5x5)	11	1,086	19.5	18
(5x5) - (10x10)	230	73,235	703.0	12
(10x10) - (15x15)	990	700,107	5,375.0	8
15x15	30	5,400	324.0	6
Total	1,261	828,428	6,421.5	

Source: Undersecretary of Fisheries.

Table 8. Employment, 1977-78 season.

Classification	Number	%
Managers	56	5.4
Technical staff	130	12.5
Administrative	43	4.1
Labor	816	78.0
Total	1,045	100.0

Source: Undersecretary of Fisheries.

significantly to regional development and social improvement, particularly in the 10th Region.

EGG SUPPLY

Unique to Chilean salmon farming is its dependence on egg imports from other countries. At the beginning, the only egg suppliers were countries of the northern hemisphere, mainly the United States, Norway and Scotland but, at present, applications to import eggs from Tasmania, Iceland, Ireland, Canada, and Finland have been submitted to the Fish Government Authorities by Chilean producers. A Chilean salmon egg supply is feasible, and local producers are making efforts to develop their own broodstock and egg supplies.

Table 9 shows the sources of egg supplies for national growers. The United States is the most important supplier for all species, Norway is second in importance, followed by Scotland. Table 10 shows the average price of eggs paid between 1987 and 1988. There is a significant difference between the price of coho eggs (US$ 25 per 1000) and that for Atlantic salmon (US$ 120 per 1000). On the other hand, the difference between the prices of coho eggs and trout eggs is not significant.

Figure 3 shows the number of eggs authorized for import for the period 1979-88, and the significant difference between the amount of eggs actually imported by the producers. No data are available for imports before 1986.

Table 9. Authorized egg imports source and quantities (x 1000).

Country	Coho	Chinook	Atlantic	Trout	Total
U.S.A.	47,860	3,910	17,460	15,953	85,183
Canada	-	1,130	50	-	1,180
Norway	-	-	10,500	3,100	13,600
Scotland	-	-	2,320	-	2,320
N. Zealand	-	500	-	-	500
Ireland	-	-	300	-	300
Iceland	-	-	2,000	-	2,000
Tasmania	-	-	2,250	-	2,250
Finland	-	-	-	350	350
					107,683

Source: Undersecretary of Fisheries.

Table 10. Eggs price (average 1987-88).

Species	Price (US$/1000)
Coho	25
Atlantic	120
Rainbow trout	20

Source: Undersecretary of Fisheries.

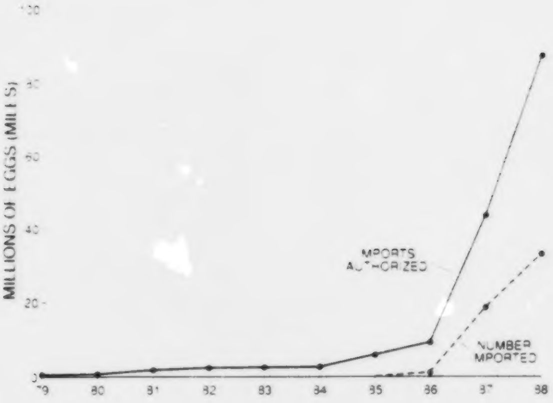

Fig. 3. Egg imports (1979-1988) salmonid species.

Table 11. Source for feed.

Source	%
Self manufacture	21
Feed suppliers	75

FOOD AND DIETS

The importance of food in the salmon farming process is evident since it is the major item in production costs. Also, dietary formulation and feed quality influence the growing rate, size and final quality of the harvest.

Most feed is produced in Chile which has abundant supplies of raw materials. There are several feed producers and there are also farmers who make their own feed. Table 11 shows sources of farmers' feed supply. Most farmers obtain feed from Chilean suppliers, 21% make their own feed and some farms buy some feed from suppliers but make some feed themselves.

Table 12 gives averages of price and feed conversion factors for dry and moist feed. It is evident that conversion values are still too high, particularly in the case of dry feed, whose value should approximate more nearly the minimum range of 1:2. There is scope for much improvement here.

MORTALITY

Mortality is a major concern for Chilean farmers since its level detracts significantly from the final production of each farm. Table 13 shows average mortality for the different farming stages. The average total mortality is 44.9%, with the major losses taking place between smolting and harvest, with mortality of 23.9%.

Mortalities are mainly caused by poor handling techniques as well as by some environmental factors. This indicates that there is a great potential to reduce mortality levels by introducing better handling techniques.

ANALYSIS OF COSTS

Table 14 shows average farm production costs. Food amounts to 42.1% of the total cost. Second in importance are salaries and egg supply, with 15.5% and 13.8%, respectively.

TECHNOLOGY DEVELOPMENT

Chilean salmon farming has not attained the technological development observed in other countries and relies on unsophisticated technological levels, particularly in relation to cage designs, feeding systems, transport and harvest. A continuous improvement can be noticed in those large companies which employ metal cages, automatic feeders, harvesting pumps, size selectors and also transport vessels. This trend will continue as companies seek means to lower costs of production.

EXPORTS AND MARKETS

The export market for the past season was centred on seven countries: Brazil, Argentina, United States, Italy, Holland, France and Japan. Tables 15 and 16 show exports in MT and dollars. We clearly observe the role of the United States as Chilean salmon importer, representing 50% of the total export market, followed by Japan which, until last season, was not a traditional importer of Chilean salmon.

The estimated export for the season is 3112 MT, which is valued at over US$ 19 million.

Table 12. Price and feed conversion (F.C.) for dry and moist feed.

Type of feed	$/kg	F.C	F.C range
Dry pellets	153	1.9	1.2-3.5
Moist pellets	90	3.4	2.0-4.0

1 US$ = $270 (Dic. 1988)

Source: Undersecretary of Fisheries.

Table 13. Average mortality for different farming stages.

Stage	%
Egg to first feeder	17.6
First feeder to smolt	12.1
Smolt to harvest	23.9
Total average	44.9

Source: Undersecretary of Fisheries.

Table 14. Average production cost.

Item	%
Feed	42.1
Salaries and wages	15.5
Eggs	13.8
Financial expenses	7.9
Packing	5.5
Repairs and maintenance	5.25
Processing	5.0
Marketing	5.0
Sanitary and health control	3.9

Table 15. Salmon exports, season 1987-88 (MT).

Country	Brazil	Argentina	U.S.A.	Japan	Italy	Holland	France	Total
Dec'87	5.42	4.00	45.36	-	-	-	-	54.78
Jan.	2.47	3.50	316.11	21.18	-	-	-	343.53
Feb.	6.95	3.00	529.91	90.55	-	-	11.60	642.01
Mar.	-	7.50	531.14	723.95	19.40	5.40	39.73	1327.12
Apr.	N/I	N/I	N/I	N/I	N/I	N/I	N/I	451.05
May	"	"	"	"	"	"	"	80.5
June	"	"	"	"	"	"	"	-
July	"	"	"	"	"	"	"	88.35
Aug.	"	"	"	"	"	"	"	41.00
Sept.	"	"	"	"	"	"	"	20.34
Oct.	"	"	"	"	"	"	"	-
Nov.	"	"	"	"	"	"	"	28.66
TOTAL								3,112

N/I: No information.
Source: Undersecretary of Fisheries.

Table 16. Salmon exports, season 1987-88 (1000 x US$).

Country	Brazil	Argentina	U.S.A.	Japan	Italy	Holland	France	Total
Dec'87	22	23	296	-	-	-	-	342
Jan	13	18	1,824	152	-	-	-	2,007
Feb	66	17	2,940	589	-	-	90	3,703
Mar	-	33	3,011	5,117	136	29	90	8,636
Apr	N/I	N/I	N/I	N/I	N/I	N/I	N/I	3,000
May	"	"	"	"	"	"	"	659
June	"	"	"	"	"	"	"	242
July	"	"	"	"	"	"	"	374
Aug	"	"	"	"	"	"	"	270
Sept	"	"	"	"	"	"	"	137
Oct	"	"	"	"	"	"	"	-
Nov	"	"	"	"	"	"	"	118
TOTAL								19,488

N/I: No information.
Source: Undersecretary of Fisheries.

REGULATIONS

Existing legislation has proved inadequate to meet the needs of the rapidly growing fish farming industry in Chile. These regulations were derived from the Fishing Activities Act and included regulations on Disease Control of Salmonidae Species and the Granting of Marine Concessions. As the industry grew, the Undersecretary of Fisheries established a few closure regulations to protect returning areas for ocean ranching in the 10th and 11th Regions. More regulations will be needed as the industry develops.

The Undersecretary of Fisheries, together with the private sector, has agreed to establish a minimal distance between sites in marine, rivers and lake areas. The regulations now require a distance of 1.5 nautical miles (about 3 km) between farms in marine waters, rivers and lakes.

THE ECONOMY OF THE CONTROLLED PRODUCTION OF SALMON

The long-term success of the national production of farmed salmon is intimately tied to this industry's economic efficiency and to the way in which this compares with that of producers in other countries. It is very difficult to form generalized concepts about the productive and economic characteristics of the companies which farm salmon in Chile because of very different structural profiles due to specialization (smolt production vs grow-out) and scale (small farms vs large, vertically integrated companies).

There is no detailed information about the economic structure of the productive process in its freshwater phase. Therefore, the market prices for smolts constitute the only source of reliable information about this subject. According to figures from Würman (1988), it can be shown, then, that coho salmon smolts are normally marketed at values between US$ 0.40 and US$ 0.60 at their place of origin and those of Atlantic salmon, with a still restricted availability, at around US$ 2.00 per unit.

With respect to the grow-out phase, the initial investment in fixed assets for growing capacities for cycles of 100-300 MT of salmon would be in the range of US$ 1000 to US$ 1500 per MT. This estimate does not include facilities for slaughtering the product once it is harvested.

Würman (1988) established that the initial total investment per harvested product MT should remain with a range of US$ 2800 to US$ 4150. In this way, the total capital requirements for a floating cage type project of 200 MT per cycle would be close to US$ 600,000, while projects for 300 MT would cost about US$ 830,000.

Costs for producing salmon in floating cages, in companies with a production capacity between 100 and 300 MT per cycle, figures from US$ 1.40 to US$ 1.90 per kilo are obtained at the producer farm level, assuming that the smolts are acquired from third parties.

Advance pro-forma calculations done for these farms indicate that coho salmon farming projects must yield internal rates of return between 13 and 32% for sale prices of about US$ 4.00 per kilo of fresh gutted salmon ready for export. The real prices for the 1986-87 and 1987-88 seasons have widely surpassed US$ 5.00 per kilo.

The local production cost figures are substantially lower than those achieved in countries like Norway and Scotland with Atlantic salmon, and in Canada with coho and chinook, species which compete with Chilean coho salmon exported fresh, mainly to the North American market. This privileged situation is partially clouded by the high air freight costs between Chile and the fresh salmon end markets. For this reason, it is feasible to consider values for the air freight between Chile and North American airports to be around US$ 1.60 per kilo of product which, together with the C&F cost of fresh gutted salmon at destination, excluding financial expenses involved, should fluctuate between US$ 4.40 and US$ 4.90 per kilo. This figure compared with the current or attainable market prices shows the excellent margin of possibility faced by national producers who work within the limits of recently established production.

PROJECTIONS

It is not an easy task to project future production, mainly because of the many unpredictable factors that affect the farming process. The most important one is mortality, whose values may fluctuate according to environmental and climatological factors, husbandry practices, predation, poaching and diseases. Another factor is average weight obtained in the harvest.

The available information on egg imports allows predictions based on reasonable estimates of expected mortality and average weights at harvest. The quantities obtained show volumes of 9233 MT for the next harvest season (1988-90) and 15,018 MT for the 1989-90 period). The national production of eggs has not been taken into acount, since no reliable estimate is available. Consequently, the projected amounts may be considered conservative unless unpredictable circumstances affect the sector and cause drastic changes.

CHALLENGES

To date, the greater part of production has been based on the import of eyed eggs. Thus, an adequate source for a national supply of appropriate quality eggs should be developed, and genetic management programs should be carried out in order to control future problems of early maturing in some species and to prolong the growth and harvest periods for others.

Today, it seems that the lack of feed manfacturing plants capable of providing the required quantities has been overcome, but there is still much to be done in specific quality control programs for raw materials, as well as for the fish diets. No less a problem is the lack of experts in the formulation of rations for salmon and, since feed is an economically critical material in the production process, more emphasis on research and development of feeds and nutrition is required.

Future production annually will require no less than 12,000 MT of quality fish meal selected for this purpose and, around 1995, this demand will surpass 30,000 MT annually.

At the present time, adequate refrigeration capacity is not available nor are the processing plants capable of slaughtering such volumes of salmon and preparing it adequately for export, either fresh or frozen. Furthermore, and assuming that the eventual exports are mainly in fresh form and by air freight, no less than 220 charter flights completely loaded with product will be required for the 1989-90 season, or possibly 1000 loading operations in airplanes partially loaded with salmon. This will represent a great challenge for the air companies as well as for the local producers.

While rapid advances have been made in fish health management, more specialized personnel in fish disease control will be required in Chile.

Another area which must receive more attention is marketing the Chilean product and the industry organization required to do this effectively. Advances have already been made with the creation in 1986 of the Chilean Association of Trout and Salmon Producers, which has faced several important challenges. One of its first activities was to establish a standard which regulates the quality of exported salmon. Compliance with these standards authorizes the exporters controlled by this system to use a seal of quality which guarantees the product's excellence for the foreign buyer.

Although this is an important advance, it is no less certain that Chilean production in the coming years will face massive competition from countries such as Norway, Canada, New Zealand, Ireland, etc. In this setting, there is no doubt that, aside from exporting salmon of excellent quality, it will be vital for producers to acquire the "brain power" to give them commercial credibility in the international markets and, even more important, that they organize themselves to set global marketing strategies. The Norwegian and Scottish experience has been successful in these areas and it is recommended that similar plans be developed in Chile.

If, in the future, current price levels might produce saturation of the demand in the already traditional fresh salmon markets, these prices will show a moderate tendency to decrease, as long as marketing strategies are not used which push consumption farther than statistical tendencies suggest. Even in this case, and with Chile having the benefit of seasonal change with respect to Northern Hemisphere producers, it is very possible that the national exporters could continue enjoying prime product prices. Nevertheless, the development of genetic research in the Northern Hemisphere leads to the conclusion that, in the medium term, this difference will not be an exclusive advantage.

Clearly, when dealing with open competition between exporters from various countries which put pressure on the same markets, and when this competition affects the sales prices, the producer with the best options for success will show the greatest economic efficiency (lower costs) to which must be added the above mentioned concepts of product quality, "brain power" and, in general, commercial credibility.

While it remains clear because of its comparative cost advantages Chile should export a highly competitive product, the Northern Hemisphere countries already have organized systems and a productive base which lets them surpass Chile with reference to these latter points.

For this reason, although a very clear national option exists for the development of the controlled production of salmon, the industry, the authorities and the scientific and technology transfer institutions must face the coming years with a high level of creativity, organizational capacity and boldness, since this period will show if the promising work done to date will become a lasting reality.

THE DEVELOPMENT OF AN INTEGRATED SALTWATER SALMONID FARMING INDUSTRY IN TASMANIA, AUSTRALIA

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ABSTRACT

Jungalwalla, P. J. 1991. The development of an integrated saltwater salmonid farming industry in Tasmania, Australia, p. 65-73. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

Attempts to establish Atlantic salmon (*Salmo salar*) populations in Tasmania at the turn of the century proved unsuccessful. Successful trials with the marine farming of rainbow trout (*Oncorhynchus mykiss*) in the early 1980's rekindled interest in salmon, led to the formulation of a strategic plan and, hence, to the integrated establishment of a marine salmonid industry.

The development has been characterized by a number of factors, including a high level of government involvement, venture capital investment by the private sector and the establishment in 1985 of Salmon Enterprises of Tasmania Pty. Ltd. (Saltas). This company has sole rights, for a defined initial period, to the propagation of Atlantic salmon. Concomitant with this status is a chartered requirement to provide a comprehensive research and development program to be funded by a preset percentage of gross annual revenue from smolt sales. A unique equity participation enables Saltas to be effectively managed as a cooperative hatchery and smolt producer for the whole industry, thereby ensuring a stable and equitable supply of smolts, on a pro-rata basis, to its shareholders.

The production sector, comprised of some 13 discrete marine farming companies, ongrows the fish to market and operates entirely according to the principles of private enterprise. Production has progressively increased to 500 metric tonnes (MT) in 1988-89, with the 1,000,000 smolts supplied to the industry in 1988 scheduled to generate 2,500 MT in 1989-90. Potential stock improvements, propagation methods and production performance are reviewed. Significant trends, major constraints and potential developments are discussed.

RÉSUMÉ

Jungalwalla, P. J. 1991. The development of an integrated saltwater salmonid farming industry in Tasmania, Australia, p. 65-73. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

Les tentatives d'implantation de populations de saumon de l'Atlantique (*Salmo salar*) au début du siècle se soldèrent par un échec. Toutefois, les essais réussis de mariculture de la truite arc-en-ciel (*Oncorhynchus mykiss*) au début des années 1980 relancèrent l'intérêt pour le saumon et aboutirent à l'élaboration d'un plan stratégique, puis à l'établissement d'une industrie de mariculture du saumon.

Le développement de cette industrie s'est caractérisé par divers facteurs, dont une importante intervention gouvernementale, le recours à des fonds de capital-risque du secteur privé et l'éstablissement, en 1985, de Salmon Enterprises de Tasmania Pty. Ltd (Saltas). Cette entreprise détient des droits exclusifs (pour une période initiale déterminée) sur la reproduction du saumon de l'Atlantique. Cette prérogative s'assortit de l'obligation d'établir un vaste programme de recherche et de développement financé par un pourcentage donné des recettes annuelles brutes de la vente de saumoneaux. Grâce à une formule unique de participation au capital-actions, la Saltas est gérée efficacement comme écloserie coopérative et entreprise de production de saumoneaux pour toute l'industrie, assurant de ce fait un approvisionnement stable et équitable de saumoneaux à ses actionnaires, au prorata de leur participation.

Le secteur de la production, composé de 13 exploitations de mariculture distinctes, élève le poisson jusqu'au stade commercial et fonctionne entièrement selon les principes de l'entreprise privée. La production est progressivement passée à 500 tonnes métriques en 1988-1989 et on estime que le million de saumoneaux fournis à l'industrie en 1988 engendrera 2 500 tonnes métriques de saumon en 1989-1990. On examine les améliorations possibles des stocks, les méthodes de reproduction et le rendement de la production et on traite des principales tendances, des grands problèmes et de l'évolution éventuelle de l'industrie.

HISTORICAL BACKGROUND

The early 1860's saw some attempts to introduce salmonids into Tasmania, but it was not until 1865 that the first formal release of Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) fry was attempted into the Plenty River of southern Tasmania. Assisted by a stocking program, brown trout populations flourished but, in spite of repeated introductions, Atlantic salmon failed to establish a breeding population. Attempted introductions of other salmonids were successful in the cases of rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*), but failed with two species of Pacific salmon (*Oncorhynchus nerka* and *Oncorhynchus tshawytscha*).

Interest in salmonids broadened from purely recreational fishing to some commercial interest with the establishment of Australia's first freshwater trout farm at Bridport, Tasmania in 1964. Some early experimentation with the seawater farming of rainbow trout was abandoned after encountering problems with water quality and the disease vibriosis. A second freshwater trout farm was established at National Park, Tasmania in 1977 and the late 1970's and early 1980's saw a series of small-scale trials with saltwater farming of rainbow trout by individuals rather than organizations. Much of this work probably duplicated the struggles being experienced by novices in other parts of the globe, but these efforts provided glimpses of a potentially bright future for the saltwater farming of salmonids in Tasmania.

The Tasmanian Fisheries Development Authority (T.F.D.A.) recognized the potential and, in 1981, began an investigation into this form of aquaculture. The work was given further impetus by the favorable assessment of the southeastern Tasmanian coastline by a visiting Norwegian salmon geneticist. Support from local industry and endorsement by the government resulted in more extensive investigations. Further visits by Norwegian advisors, and later by Norwegian interest groups, helped to formulate, in late 1983, an interim plan for the establishment of an industry.

In October 1983, it was envisaged that majority funding by the government would provide a secure financial base to a "Salmon Enterprise Foundation," which could reliably provide stock and an advisory service during the formative years of a hitherto nonexistent industry. It was envisaged that a relatively strong Norwegian representation in the private sector could be adequately balanced by agreements on the provision of technical advice to result in a net advantage to Tasmania. Further, it was envisaged that the Tasmanian private sector was both desirous and capable of using the above provisions as sufficient springboard to launch an industry.

It was proposed that the industry be based mainly on salmon, with rainbow trout retaining a niche, but with less obvious potential for additional commercial development. A pre-existing ban (since 1968) on the importation of fresh salmonid products into Australia meant, therefore, that the source of salmon was restricted to landlocked stocks of Atlantic salmon in the State of New South Wales, or chinook salmon in the State of Victoria. The status of each population was carefully assessed. Atlantic salmon was selected because of the specific pathogen-free status of the available stock, the apparent similarities between the Norwegian experience and Tasmanian conditions and a perceived marketing advantage.

The Atlantic salmon were of Canadian origin, from the Cobequid hatchery (River Phillip stock) in Nova Scotia. They were known to be a large, genetically sound, late maturing population. The fish had been introduced into the government hatchery at Gaden in New South Wales in three imports between 1963 and 1965. To date, they have not established a wild breeding population and are released annually for lake stocking from the Gaden hatchery.

With a view to further protecting the Tasmanian salmonids' "disease-free" status, a quarantine protocol was developed involving the Departments of Agriculture, Sea, and Inland Fisheries. The Gaden broodstock were isolated and put through an exhaustive disease testing program under the auspices of the Australian Fish Health Reference Laboratory (A.F.H.R.L.) for 18 mo prior to stripping. At the end of July 1984, having passed all tests, the first 115,000 Atlantic salmon ova were shipped to Tasmania. After spending 15 mo in a specially created quarantine facility at the T.F.D.A.'s Research Laboratory, 36,000 of the best smolts were transferred to seawater cages to become foundation stock for the industry; the rest were destroyed. Subsequent imports from Gaden in 1985 and 1986 (180,000 and 375,000, respectively), under similar protocol, supplied stock to the Tasmanian industry while the 1984 year-class fish completed a cycle to provide the first Tasmanian-reared progeny in 1987.

THE PROPAGATION SECTOR

In February 1985, Salmon Enterprises of Tasmania (Saltas) was established under the Salt-Water Salmonid Culture Act 1985 of the Tasmanian Parliament. The initial equity participation of Australian $2.5 million in Saltas was: Tasmanian government - 51%, the Norwegian company, Noraqua - 19%, and the Tasmanian private sector - 30%. The company was to operate a hatchery and smolt production unit at Wayatinah, a model sea farm at Dover, and a research foundation to aid the developing industry. Saltas was established with the following general objectives:

- Establishing and developing a high quality broodstock of Atlantic salmon and trout, adaptable to saltwater culture by a program of selective breeding and genetic research.
- Producing at least one million smolts/yr for commercial culture in salt water.
- Financing and operating a research and selective breeding centre and hatchery and a model sea farm capable of producing approximately 100 MT of fish/yr.
- Training of suitable and qualified staff.
- Operating in all the above matters as a commercial venture.

The Parliamentary Act inaugurating Saltas also accorded Saltas the exclusive license to operate an Atlantic salmon hatchery in the State for the first 10 yr. With a banning of further imports of stock into Tasmania for disease quarantine reasons, all smolts would therefore originate from Saltas. The entitlement to purchase of smolts from each year's production was defined on a pro-rata basis, according to equity shareholding in Saltas. The government share of 51% in equity only attracts 1% of the total smolt production for broodstock and research purposes required by Saltas.

Concomitant with the exclusive smolt producer status, came a requirement embodied in the Articles of Association to provide a comprehensive Research and Development Program to be funded by the application of a minimum of 25% of the gross revenue to Saltas from smolt sales to the industry. The program is monitored, revised and recommended to Saltas by a Research Committee to provide government agencies, the aquaculture education sector, Saltas and, most importantly, the private sector, involved in saltwater farming. This represents an efficient mechanism for channeling available funds (currently somewhat in excess of Aust. $600,000 per annum) to the most relevant applied research topics.

Due to an accelerated development program and cost escalations associated with building a sophisticated hatchery, 90% equity in Dover sea farm was sold by Saltas in October 1986 to Tasmanian Atlantic Salmon Limited, a public company listed on the Stock Exchange. This company restructure resulted in a capital injection of about Aust. $1.6 million to assist with funding developments.

The concern that all smolt production was being generated at one facility has been partly allayed by building that facility to high standards, and with an elaborate deployment of simple backup measures. The residual risk has been deemed unavoidable in the short term but a second, satellite facility which will spread the risk is now underway.

Saltas now operates a state-of-the-art hatchery and smolt production unit, ensuring a stable and equitable supply of smolts to its shareholders, the Tasmanian Industry. It has also provided support through a number of applied research projects ranging from fish biology to aquaculture technology, and is engaged in a comprehensive stock improvement program.

The encouraging seawater trials with trout and the general level of interest in the developing salmon project in the early 1980's prompted the two existing freshwater trout farming companies to diversify into fingerling production. The combined production capacity of the hatcheries operated by these companies is now in excess of 1.5 million fingerlings/yr at 300 g each, or greater numbers at lower weights. Trout fingerlings are available to the industry throughout most of the year. Fish from 80-500 g are acclimatized under varying regimes to provide a choice of production strategies, depending on individual management preferences and site factors. This sector of the industry has capacity to increase production rapidly as there are no controls on hatchery output.

During the initial years of salmonid development, growers have been encouraged to farm rainbow trout while supplies of Atlantic salmon smolts remained restricted. In many cases, technology imported for salmon propagation has benefitted the trout hatcheries and experience gained in sea farming rainbow trout has been applicable to salmon.

The Salt-Water Salmonid Culture Act also ensured that the trout hatcheries were not commercially disadvantaged by restricting Saltas' commercial activities with rainbow trout.

THE PRODUCTION SECTOR

By mid 1987, 21 marine farming permits (leases) for salmonid farming had been issued in Tasmania, and a further 15 applications were pending. There has since been a moratorium on the issuing of leases in certain areas and rationalization of site use such that some 18 sites are now in use by 13 separate farming companies. Lease sizes range from 1.5-14.0 ha (with an average of 5 ha), and locations range from brackish water to fully oceanic conditions. Most sites are in close proximity to a land-based facility and some have access to sufficient fresh water for acclimatization.

After some early experimentation with various designs, most companies have settled with locally manufactured circular polyethylene cages of 13 and 20 m diameters. Automated feeder systems are in common use and fish pumps are presently being tested for fish in saltwater operations. Although the companies have yet to reach full-scale production, it is estimated in broad terms that it will cost Aust. $1 million for capital development and 5 man-units per year for each 200 MT of annual production. These figures exclude processing facilities or processing costs.

While stock purchases remain a major budget item for farmers, smolt prices are maintained at a comparatively modest level and are forecast for several years ahead of production. The 1989-90 price is set at Aust. $2.40 each for vaccinated smolt between 50 and 120 g delivered to any farm. There is no premium for larger smolt, but each shareholder receives his pro-rata allocation across the full range of sizes available in that season. Shareholders are at liberty to redistribute their allocation, providing it is to another licensed marine farm. Rainbow trout fingerlings are presently being traded at about Aust. $6.30/kg, ex hatchery, for fish of most weights.

A favorable temperature profile, generally between 8 and 18°C, assists in achieving a particularly high growth rate for Atlantic salmon in Tasmania. After approximately 15 mo in salt water, a harvest weight of 4 kg live weight under most conditions is considered normal. For rainbow trout acclimitized at 250 g, a market weight of 1.8 kg can be expected within 8 mo of saltwater growth.

Local feed manufacturers and Saltas have jointly undertaken considerable research and development in areas of ration formulation and pellet manufacture. As a result, a suite of high standard feeds is now being supplied to the industry. Feed costs ex-factory, and including pigments, are about Aust. $990/t and $1090/t for trout and salmon grower rations, respectively. Food conversion ratios being achieved vary widely between farms, depending on site factors and management capabilities, but an industry average appears to be 1.8:1 for salmon and 2:1 for trout.

Fish mortality remains the greatest single variable between farms and will be a permanent concern in the industry. Diseases such as vibriosis, a gill amoeba and lately a marine flexibacter, can cause rapidly escalating and severe losses under the warm water conditions of summer. In each case, appropriate control measures are being investigated. Predation by seals has been a problem and a research project is underway to develop an environmentally and commercially acceptable method of seal control.

While sound management practices on some farms have maintained mortality rates well below 20%, others have lost up to 50% of stock in a season. It is expected that an industry average will emerge at about 22% per annum.

As a measure of overall performance relating the number of smolts purchased to the final output in kilos of salmon harvested, the concept of "smolt equivalent" is commonly used. Industry average smolt equivalent for 1987-88 was 1:2.9 kg. It is expected that a smolt equivalent of 1:3.2 kg will be achieved simply in overcoming the teething troubles of a new industry.

Six of the farming companies have their own processing facilities. Most of these are specialist operations for the processing and packaging of rainbow trout and Atlantic salmon, maintained to export certification standards. In recognition of Australian climatic conditions and the distance from major markets, all the processing facilities have adopted high standards in the handling, processing and distribution of the product. The vast majority of the product is distributed as fresh chilled or cold smoked.

The marketing of both salmonid species is currently being undertaken by a few of the larger participants in the industry. In some cases, several producers supply one marketing organization. The market reception of the product during its initial launch was very favorable, but the quantities involved to date have been relatively small (1988-89 production of salmon about 500 MT and trout about 1200 MT). With an immediate domestic demand likely to be no more than 2000 MT of both species and with the 1989-90 production estimated to be some 3500 MT, companies have begun to develop an orderly marketing strategy and a cooperative export development program.

During the 1988-89 season, prices for fresh dressed and packed fish ex processing factory have been in the order of Aust. $15.00/kg for salmon and $10.00/kg for trout. In the longer term, it is considered unlikely that these prices will be maintained as supplies increase and a price reduction in the order of 20% is forecast. It is estimated that gross revenue for the Tasmanian salmonid industry in 1989-90 will be about Aust. $40 million.

MAJOR CONSTRAINTS

To date, the Atlantic salmon introduced to Tasmania have not shown evidence of any undesirable genetic characteristics after having been a closed, landlocked population in N.S.W. for in excess of 20 yr. It is fortuitous that the fish are demonstrating particularly good biological performance in terms of growth rates and food conversion ratios under most farming conditions. Given the Australian Department of Primary Industry's extreme reluctance to break the import ban (for very valid disease quarantine reasons), any stock improvement has to be achieved by work with the existing gene pool.

The capacity of the production sector to undertake quantum expansion is restricted by site availability. Compared to sea farm sites in other areas of the world, Tasmanian sites tend to be shallower, with less water movement and subject to higher water temperatures. Despite these known constraints, it will be a number of successful harvests before the level of industry confidence rises enough to implement offshore farming or the use of technically advanced floating raceways on any large scale.

A potential problem in the rapidly developing industry is the seasonality of production. Seasonal peaks traditionally lead to a cycle of market saturation during main harvest and a subsequent loss of markets and product substitution during the interval. The main harvesting season for Atlantic salmon is currently from September to March, prior to the fish reaching maturity. With rainbow trout, the harvesting season can be extended but a seasonal peak is likely during spring and early summer. A number of measures have been implemented to reduce the impact of seasonal peaks, either by extending the seawater phase prior to maturation, or by producing non-maturing fish and all female stock.

Investment in the salmonid industry in Tasmania is still regarded as being venture capital. Notwithstanding an encouraging start, the industry is largely unproven in terms of commercial production history. As a matter of policy, measures have been taken to reduce the potential risk for investors, and part of Saltas's brief is to seek, evaluate and apply the latest available technology to the industry. Such information is partly provided through formal agreements with the Norwegian participants, but much of it must be gleaned by Saltas research and industry experience. High anticipated returns from salmonid production appear to compensate for the level of risks involved.

Unlike the gradual evolution from harvest fishery to fish farming as has occurred in Norway, Scotland and Canada, caged culture of salmonids in Tasmania has practically emerged overnight. The industry therefore has not had the benefit afforded by the presence of research institutions with a history of relevant experience, nor by an available industry infrastructure to call on for materials and technology. In response to the bourgeoning aquaculture industry, local feed manufacturers, suppliers of specialized equipment and the transport sector, are now rising to the challenge. The government departments which have been involved since the planning stages in their various capacities are increasing commitment to financial, administrative and research support. The aquaculture education sector, centred at the Tasmanian State Institute of Technology, is now able to offer postgraduate courses in aquaculture through its School of Applied Science.

TRENDS AND POTENTIAL DEVELOPMENTS

Australia generally, and particularly Tasmania as an island state, is relatively pathogen and disease free compared to other world production areas. None of the viruses recognized to produce salmonid diseases has been found in Australia, and neither has furunculosis, bacterial kidney disease nor whirling disease. A form of *Yersinia* (*Y. ruckerii* Biotype 3) has been identified and tentatively called salmon blood spot disease (mortalities attributable to S.B.S. are about 0.1% per annum). This low level of disease incidence has been recognized as an asset, and the total ban on the import of fresh produce and genetic material is likely to remain. The disadvantage of genetic isolation is considered to be compensated for by the advantages of quarantine.

In an Atlantic salmon hatchery, an indication of performance is the S1 rate, or the percentage of fish smolting after 1 yr in fresh water. In the 4 yr of observation under Tasmanian conditions, S1 percentages have averaged 97%, with the smoltification "window" appearing as a 6-wk period between mid-September and mid-November. While it is a highly regarded asset of the stock, a high S1 rate and narrow window nevertheless poses a logistical problem at time of smolt transfer and underutilizes the full capacity of the hatchery at certain times of the year.

A second phenomenon which serves to compact the production cycle is the fact that a high percentage of the stock mature after their first year in salt water. It is not a conventional "grilse problem" in that the bulk of the harvested fish still range from 3-5 kg and are in excellent condition, showing none of the characteristic grilse traits. Rather, it creates a strong seasonal trend by setting a limit on harvest prior to maturation.

Much of the developmental work on biological performance is therefore aimed at spreading the production cycle, either by bringing forward the time of smoltification, or by postponing maturity.

Thus, 1989 will see the implementation of a series of trials aimed at using photoperiod manipulation to bring smoltification forward in order to extend the seawater phase prior to maturation. Further, it has been observed that a small percentage of the stock does smoltify in the autumn of their first year (so, autumn smolts) and a breeding project to develop a line of fish with this trait is underway. A second line of salmon also being developed is derived from fish which do not mature until they have spent 2 yr in salt water. This "Salmon Line" will allow harvesting to be extended beyond present limits and, on casual observation to date, provides fish in the 8- to 12-kg range after 2 yr in the sea.

A comprehensive selective breeding program has been the subject of intensive discussions for some time. It is as yet unresolved whether, and at what stage of industry development, the cost of a full family-based selection program can be justified. It is likely that a combined selection program (i.e. selection of individuals from a group of families) will supersede the current mass selection program.

The production of non-maturing fish has been the subject of intensive review by the Research Division of Saltas. General consensus has been that, despite the scientifically documented low risk level to consumers, there is likely to develop adverse market reaction to stock which has been directly exposed to hormonal, chemical or irradiation treatment at any stage of its production.

Saltas has therefore embarked on a project of all female triploid production. Male hormone has been administered to batches from two year-classes of fish and the resulting sex-reversed female fish will be crossed with normal females during the 1989 season to attempt the first production of all female stock. Concurrently, hydrostatic pressure shock has been used over a band of treatment regimes to identify optimum treatment for industrial production of triploid stock. Results from these experiments have also been encouraging, with preliminary data suggesting that triploid yields of 90-95% have been achieved on an experimental scale. The trout hatcheries have concentrated their efforts mainly on the production of all female stock, and are somewhat further advanced in this direction.

Developments in the production sector are likely to be primarily in the direction of improving productivity on existing sites, and secondly in the direction of utilizing less conventional sites and production methods.

Thus, the introduction of new technology is an obvious area of ongoing development which may require both industry and government support. Given the capital intensive nature of the industry, it is necessary to ensure all potential new technology is adequately researched to evaluate suitability to Tasmanian conditions. In an attempt to rationalize facilities, adjustment of stock or contract growing is likely to become more prevalent.

Suitable sites for salmonid marine farms are becoming relatively scarce with new sites providing marginal suitability either in terms of hydrology or in terms of potential competing usage. Public opposition to the granting of additional permits is mounting, and this has already prompted the industry to adopt measures ensuring marine farms and service facilities are developed and maintained to complement the environment.

In the longer term, as the availability of inshore sites becomes exhausted, it will be necessary to look at either offshore or land-based sites. The higher capital costs are likely to be offset by the relatively large throughput serving to reduce per-unit costs. The floating raceway concept, with its induced water flow, will overcome the problem of poor water movement in many areas. The development of larger cages suitable for deep, open-water mooring will make accessible large tracts of water presently considered unsuitable because of periodic rough weather. Shore-based, pumped water facilities would make usable much of the coastline where excellent quality seawater is too shallow for cage mooring.

It is unlikely at this stage that any additional salmonid species will be recommended for commercial development in Tasmania. Apart from the physical limitations on site availability and environmental factors, the risk to the present industry of introducing additional diseases is of concern. It is also unlikely that ranching of salmon will be recommended in the foreseeable future. Apart from the unknown potential of feeding grounds and migrations in Tasmanian waters, the legal and administrative problems likely to arise are considered daunting.

Since the importation of salmonids (other than those which have been heat treated) is prohibited into Australia, the main competition to sea-run rainbow trout and Atlantic salmon is from other gourmet seafoods. These include barramundi, reef fish, crustaceans and shellfish. However, when compared to some of these products, salmonids are very price competitive. Efforts are being intensified to ensure that salmonid import regulations are realistically enforced. A progressive stepping up of production will allow the companies concerned to develop marketing strategies to cope with the expansion. This includes undertaking product development, domestic and export market promotion, and the building of product awareness among consumers.

Atlantic salmon and sea-run rainbow trout are gourmet products in the market place commanding premium prices. As with many products in this category, there is a very high incentive for producers of similar but lower rated products to attempt substitution. Substitution has been attempted with the replacement of sea-run rainbow trout and Atlantic salmon with freshwater rainbow trout produced elsewhere in Australia. As the industry develops in the State, steps are being taken to ensure the produce has its own established identity. This is being attempted with the maintenance of high standards during processing, good packaging which identifies the product, proper promotion and regular followup in the market place.

Predictions are never certain but there appears a potentially bright future for the saltwater farming of salmonids in Tasmania, and there exists an enormously strong will to succeed.

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HEALTH PROTECTION FOR SALMONID RESOURCES IN CANADA

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ABSTRACT

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Canada has extensive, economically important natural salmonid resources. A wide range of measures, many of which impact on aquaculture, have been developed to protect the health of these resources. They focus on minimizing the risk of introduction and dissemination of communicable diseases, and include national regulations, regional fish health protection initiatives and provincial regulations and policies. Industry-related hazards are controlled through regulations concerning movement of research materials, feed manufacture, importation and production of biologics and use of drugs and therapeutics. A strong R&D capability in Canada supports technological innovation for the prevention, treatment and control of diseases and provides the basis for developing and refining fish health protection regulations and policies. Programs for training and skill development in the fish health field are also expanding. These measures have been effective in preventing the introduction of selected pathogens previously unrecorded in Canada, and confining diseases that have limited geographic distribution. They have also helped create a favorable climate for major investments in salmonid farming and supplementary industries. Future activities are likely to focus on development of continental approaches to fish health protection and refinement of legislation and compliance protocols as new technologies are developed and the data base on fish diseases increases.

RÉSUMÉ

Carey, T. G. and G. I. Pritchard. 1991. Health protection for salmonid resources in Canada. p.75-84. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, Feburary 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

Le Canada dispose de vaste ressources de salmonidés naturels, d'une grande importance économique. Il a conçu un éventail de mesures, dont certaines ont des effets sur l'aquiculture, pour protéger la santé de ces ressources, principalement pour réduire les risques d'introduction et de propagation de maladies transmissibles. Ce sont notamment des règlements nationaux, des mesures régionales de protection de la santé du poisson ainsi que des règlements et des politiques provinciales. Les dangers inhérents à l'industrie sont enrayés au moyen de règlements sur les mouvements de

spécimens destinés à la recherche, sur la fabrication des aliments, sur l'importation et la fabrication de produits biologiques et sur l'usage de drogues et de substances thérapeutiques. Au Canada, de nombreuses installations de recherche et de développement appuient les innovations technologiques en matière de prévention, de traitement et de supression des maladies et constituent une plate-forme de développement et d'amélioration des règlements et politiques de protection de la santé du poisson. On intensifie également les programmes de formation et de développement des compétences dans le domaine de la santé du poisson. Toutes les mesures précitées sont parvenues à empêcher l'introduction de certains pathogènes, autrefois inconnus au Canada, et la propagation de maladies qui ne sont confinées qu'à certaines zones géographiques. Elles ont également permis de créer un climat propice aux grands investissements dans la pisciculture des salmonidés et dans les industries complémentaires. À l'avenir, on s'attachera vraisemblablement à concevoir des approches continentales à la protection de la santé du poisson et à améliorer la législation et les protocoles d'exécution, compte tenu de l'apparition de nouvelles technologies et de l'acroissement des bases de données sur les maladies du poisson.

INTRODUCTION

Wild salmonid resources are extensively distributed throughout Canada, supporting commercial harvests, native food fisheries and recreational fisheries of major significance to many regions of the country. The largest of these regional fisheries is for Pacific salmon, where the commercial saltwater catches alone in 1987 amounted to 66,695 metric tonnes (MT) valued at 212 million Canadian dollars. Also, commercial aquaculture industries for salmon in coastal waters are in a rapid growth phase, and there are well established trout farming industries in several provinces, particularly Ontario, Quebec, Saskatchewan and British Columbia. One of the major deterents to the development of the natural resources has been the risks from fish diseases, requiring the aggressive application of prevention, control and eradication practices and supporting regulations that, to a large extent, were pioneered in Canada over the past decade.

This has been no mean task, as fish health protection is a relatively new area of scientific endeavor. Moreover, diseases are easily disseminated but difficult to eradicate, they affect wild and cultured stocks alike, they have uneven distribution within the country and effective methods of control are not always available. Also, fish disease problems involve populations and not merely individual fish, requiring mechanisms that more closely parallel plant protection models; those in veterinary science for treatment of domestic animals do not necessarily apply. Also, communicable diseases present unique vector problems because of the aquatic medium in which they are found. Finally, they know no jurisdictional boundaries, hence effective collaboration among governmental agencies, research centers, resource managers and private producers has been dictated.

Fortunately, Canada has enjoyed having a wealth of expertise distributed throughout governments, universities and the private sector that is so essential for addressing the changing needs of health protection measures. There has been much agreement among experts on the severity of disease problems and actions required, leading to a degree of professional cooperation that is more advanced than in most other fields of aquaculture science. Protection of fish from infectious diseases also has been recognized in political as well as scientific circles as central to preserving options for habitat use, husbandry of the wild resources and intensive production systems deploying aquaculture technologies. This enabled the federal Department of Fisheries and Oceans of Canada, which has a nation-wide legal responsibility under the Fisheries Act for the management and development of fisheries related to these important natural fisheries resources, to readily exercise its mandate to protect the health of these resources.

Administration of fisheries in Canada is, however, very complex in that there are 12 distinct geographic/jurisdictional zones (10 provinces and two territories). Provincial agencies have been delegated administrative responsibility for fisheries in four of the provinces, the Yukon territory has recently signed an agreement to administer its fisheries, responsibilities for fisheries management in British Columbia and Quebec are separated into freshwater (provincial government) and marine (federal government). The federal Department of Fisheries and Oceans, whose organizational units do not necessarily follow provincial boundaries, administers fisheries in the remaining four provinces (Newfoundland, Nova Scotia, New Brunswick and Prince Edward Island) and one territory (Northwest Territories). Control of industry-related hazards also involves regulations administered by federal agencies other than the Department of Fisheries and Oceans (e.g. Departments of Health and Welfare, Transport, Environment and Agriculture). Despite these complexities, a broad program is emerging which provides effective fish health protection in Canada. Many of the measures that have been implemented impact on commercial aquaculture since it is in the areas of intensive production systems where fish health management principles are most central. Success, to a large degree, can readily be attributed to collaboration between interested parties, and the recognition by producers and provincial/regional and national authorities of their obligations to participate in the control of communicable fish diseases.

This paper outlines firstly the conceptual framework within which fish health policies have emerged in Canada, providing both an indication of the scope and nature of the disease threats and accountabilities expected. It then describes the responses which have followed in terms of programs on a national, regional and provincial basis, and identifies possible future directions.

CONCEPTUAL FRAMEWORK

Responsibility for protection of aquatic resources for the benefit of the common interest is vested in governments with powers which must be exercised at the regional or mesogeographical levels. This includes control of communicable diseases, the objective of which is to minimize risks of introduction and dissemination of diseases to natural stocks from potential disease sources. Those with the designated administrative authority must take necessary measures to assure this protection using administrative options implemented as acts, regulations, policies or guidelines, and balance the need for control with the need to operate efficient and economical fish production units. Resource managers must also make decisions which focus on risk management rather than absolute protection.

Public policies also are needed for the protection of innocent parties that might be affected by the actions of others. Water presents a fluid environment that can quickly and easily carry fish pathogens across considerable distances from a disease source, a feature which must be recognized. Consequently, producers who have worked hard to minimize risk of disease outbreaks may have their efforts negated by less conscientious operators upstream of their facilities. Similarly, the production of vaccines, fish feeds and therapeutics has potential fish health risks, and the use of these products needs to be reviewed and regulated by governments.

Fish culture facilities tend to be the primary sites for disseminating fish diseases because of increased susceptibility of fish to diseases when reared in high concentrations or in artificial environments. Owners and managers of private facilities must be called upon to recognize the potential for dissemination of diseases to the natural environment from facilities under their control, and the associated liabilities. Diseases can be disseminated through hatchery effluents, poor hatchery sanitation procedures or through interstation transfer or release of infected eggs and fish. Other hatcheries in the same watershed and, in some cases, natural fish populations can be affected.

Governmental agencies must also be accountable for the conduct of their own fish culture programs and for setting an example for the private sector. In many instances, production by government stations and scope of distribution to rivers and lakes far exceeds that of the private sector; thus, the risk of disease dissemination through release of stocks from government facilities is high.

In the event of eradication of diseases from specific zones by stock destruction, agencies which initiate depopulation action may be requested to provide compensation for destroyed stocks, at least to the extent that would allow an operator to stay in business. In practice, *ex gratia* payments have been made in selected cases, as compensation funds do not now exist and the establishment of such funds for specific named diseases would be difficult and administratively cumbersome.

There are several types of fish diseases of concern, classified here as infective, genetic, physiological, ecological (e.g. stress), nutritional, neoplasties (e.g. cancers) and toxicological, although this paper addresses only the infective or communicable diseases caused by viruses, bacteria and parasites. Implied in the characterization of infective diseases is the ability to identify and detect a causative organism.

In Canada, the communicable diseases of major concern over the last decade include:

Viruses:	Viral Hemorrhagic Septicemia (Egtved virus, VHSV) Infectious Hematopoietic Necrosis (IHNV) Infectious Pancreatic Necrosis (IPNV)
Parasites:	Whirling Disease (*Myxobolus/ Myxosoma cerebralis*) Ceratomyxosis (*Ceratomyxa shasta*)
Bacteria:	Furunculosis (*Aeromonas salmonicida*) Enteric Redmouth Disease (*Yersinia ruckeri*) Bacterial Kidney Disease (*Renibacterium salmoninarum*)

Two of these diseases, VHSV and whirling disease, have yet to be detected in Canada (Table 1), although whirling disease has been recorded in several states of the U.S.A. that

Table 1. Record of communicable fish diseases in provinces/territories of Canada.

	Viruses			Parasites		Bacteria		
Province/territory	IHN	IPN	VHS	Whirling disease	Ceratomyxosis	Furunculosis	Enteric redmouth disease	Bacterial kidney disease
Newfoundland/Labrador	-	•	-	-	-	-[a]	•	•
Nova Scotia	-	•	-	-	-	-[a]	•	•
New Brunswick	-	•	-	-	-	•	•	•
Prince Edward Island	-	•	-	-	-	-	-	•
Quebec	-	•	-	-	-	•	-	•
Ontario	-	•	-	-	-	•	•	•
Manitoba	-	•	-	-	-	-	•	•
Saskatchewan	-	-	-	-	-	-	•	•
Alberta	-	•	-	-	-	-	•	•
Northwest Territories	-	•	-	-	-	-	•	•
Yukon	-	•	-	-	-	-	-	-
British Columbia	•	•[b]	-	-	•	•	•	•

[a] Only "atypical" biotypes of furunculosis have been detected in Newfoundland and Nova Scotia.

[b] The first record of IPNV in British Columbia was confirmed in September 1989.

border Canada. With the exception of Bacterial Kidney Disease (BKD), which is now considered widespread but not necessarily in all production facilities, the other pathogens of concern have uneven distribution across the country. Significantly, IHNV and ceratomyxosis are confined to the province of British Columbia, and only recently has IPNV been confirmed in that province. *Aeromonas salmonicida* has been detected in Nova Scotia and Newfoundland, but the disease agents were "atypical" biotypes and not the non-motile aeromonad typically causing the disease fununculosis.

FISH HEALTH PROTECTION REGULATIONS AND RELATED NATIONAL PROGRAMS

The most significant national thrust in recent years towards provision of fish health protection related to salmonids was the implementation in January 1977 of the Fish Health Protection Regulations (FHPR) under Section 33(b) of the Fisheries Act of Canada. Coincident with promulgation of the Regulations, a Manual of Compliance was issued to outline the administrative, inspection and sampling procedures; it also included disease detection methodologies for the major bacterial, viral and myxosporean pathogens of salmonids. All other matters that relate to fish quality and public health safety come under the Fish Inspection Act.

The Regulations apply only to fish species belonging to the family Salmonidae, and are designed to prevent the spread of infectious diseases through inspection of fish stocks in production facilities and control of the movement of infected fish. They apply to live and dead cultured fish, eggs (including any fertilized or unfertilized sex products) of cultured and wild fish, and products of dead cultured fish destined to move into Canada or across provincial boundaries within Canada. All movements of salmonids into Canada or between provinces require a permit. In the event of violation of the Regulations, seizure and other powers of the Fisheries Act apply.

Other features of these Regulations include:

- Production facilites, not individual fish lots, are certified free of named diseases.
- Different risks are perceived for movement of live fish and eggs, and for products of dead fish.
- Fish Health Certificates are only issued to facilities after a satisfactory disease history is obtained.
- The FHPR represent the first set of truly national fisheries regulations, but are administered within provinces by local Fish Health Officers.
- The concept of zoning has been introduced on the basis of detailed information relating to the absence of disease agents in specific areas; the zoning concept has only been applied to facilities exporting dead cultured fish.

In support of the FHPR, Canada now recognizes 143 Fish Health Officials in 15 countries; these officials are approved to inspect and certify culture facilities according to procedures outlined in the Manual of Compliance to the Regulations. There are currently 163 facilities in five countries that are being inspected and certified under the FHPR.

Since inception, the Regulations have been amended once (1987) to transfer BKD from the list of "certifiable" diseases to the list of "notifiable" diseases. This action was taken in recognition of the apparent widespread distribution of BKD in Canada as determined through more sensitive diagnostic techniques and the willingness of fish health administration officials in each province to decide whether to permit importation of fish infected with BKD. The Manual of Compliance was revised and updated in 1984.

Also established in 1977 was the National Registry of Fish Diseases, which has served as a center for the documentation and dissemination of information pertaining to fish diseases in Canada. Fish Health Laboratory Reports of all disease examinations conducted in Canada under the FHPR have been submitted routinely to the Registry. Collectively, these records now form a substantial data base for governments on the presence (or absence) of infectious diseases in all regions of Canada, and provide a valuable reference for assessing proposals for future changes to the Regulations.

The National Registry of Fish Diseases provides a focal point for other actions relating to fish health production, including:

- maintaining a close watch on the geographic distribution and prevalence of fish diseases in Canada and identifying emerging disease problems;
- serving as a coordinating center in the event of national fish health emergencies;
- providing periodic reports, analyses, and assessments of the state of fish health in Canada; and
- identifying and evaluating new risk situations for the introduction and dissemination of communicable diseases.

The FHPR has had an impact on trade in salmonids and control of disease. Patterns of stock movements permitted under the Regulations have changed over the years. Total numbers of live fish and eggs imported and transferred between provinces have decreased, and the emphasis now is on transfer of eggs rather than juveniles. There have been no outbreaks of communicable salmonid diseases traceable to movements of fish or eggs that were authorized under the Regulations. Also, diseases of concern such as VHSV and whirling disease have not been introduced to Canada, and there has been containment of diseases within known geographic areas (e.g. IHNV and ceratomyxosis are still confined to British Columbia).

Hazards of communicable diseases may also be created by the movement of causative organisms or health-related agents such as research materials, feed ingredients and biologics. Similarly, drugs or therapeutic agents that may affect the character of pathogens or overall health of fish should be subject to regulated usage. In Canada, measures presently in force to address these hazards include:

- **Research materials** - The importation and testing of a range of research materials (e.g. new drugs and therapeutics) are controlled under the Food and Drugs Act. The Minister of the Department of Fisheries and Oceans can also authorize the transfer of eggs and fish for research purposes under Section 4 of the Fisheries Act.
- **Feed Ingredients** - Production of fish feeds is subject to provisions of the Animal Feeds Act, administered by the Canada Department of Agriculture.
- **Biologics** - The importation, production procedures, testing and sale of biologics (e.g. vaccines, antisera for diagnostics, etc.) are subject to provisions of the Animal Disease and Protection Act administered by the Canada Department of Agriculture.
- **Drugs** (anti-microbials) - Prescriptions for treatment of fish disease outbreaks with drugs and therapeutics can only be issued by veterinarians. Approval of drugs to be used in aquaculture is given under the Food and Drugs Act administered by the Canada Department of Health and Welfare.

The Department of Fisheries and Oceans (DFO), with its mandate to conserve and protect wild resources, has been undertaking a range of fish health activities related to its own needs; many of these have spin-off benefits to the aquaculture industry. Basic research, particularly related to salmonid diseases, is conducted at DFO laboratories in St. John's, Halifax, Burlington, Winnipeg and Nanaimo. Studies include research on identification, histopathology, immunology, transmission and control of viruses, bacteria and parasites. Research on diseases of aquatic organisms is also conducted with federal funding at an increasing number of universities across Canada, including the Atlantic Veterinary College, University of Montreal (St. Hyacinthe), University of Guelph, University of Alberta, Simon Fraser University and University of Victoria.

REGIONAL FISH HEALTH PROTECTION MEASURES

Specific diseases and the problems they create differ between regions, and there are now several examples where government agencies and, in some cases, the private sector have collaborated to establish fish health protection programs for definable regions. One example is the policy and model fish health protection program developed by the Great Lakes Fish Disease Control Committee (GLFDCC) which comes under the Great Lakes Fishery Commission. The Commission coordinates fisheries management and development in Lakes Superior, Huron, Michigan, Ontario and Erie, and all watersheds which flow into these lakes. The fish health protection policy adopted by the Commission encourages member agencies to:

- develop legislative authority and regulations to allow control and possible eradication of fish diseases;
- prevent the release of seriously infected fish;
- discourage the rearing of diseased fish;
- prevent the importation, into the Great Lakes basin, of fish infected with "emergency" diseases (i.e. diseases of concern that have not been detected in the Great Lakes basin);
- prevent the transfer, within the Great Lakes basin, of fish infected with "restricted" diseases (i.e. diseases of concern that have been recorded within the Great Lakes basin); and
- eradicate fish diseases wherever possible.

A model fish health protection program prepared by the GLFDCC is endorsed by the Great Lakes Fishery Commission. The recommendations set out in the model program are provided as an aid to member agencies and other participants (including the private sector) in controlling fish diseases, and includes sections related to basic obligations of agencies and organizations, application of the program in terms of specific diseases and activities, describes importation protocols and control measures related to transfer and release of fish. Canada participates in this regional program through representation from the Department of Fisheries and Oceans, Ontario Ministry of Natural Resources and Ontario Trout Farmer's Association. Other participants include the U.S. Fish and Wildlife Service, State agencies and some private producers that operate salmonid hatcheries within the Great Lakes basin.

While the policy and model program are not legislated (adherence has been accomplished through peer pressure from consensus decisions made by the GLFDCC), they have been found to be workable over the past 14 years. There has been a general raising of consciousness of disease risks, and a degree of uniformity and cooperation has been introduced in application of fish health protection across the region. With the success of this model, similar programs have evolved for the Colorado River system, the Pacific Northwest (including the Columbia River and its tributaries) and New England. The feasibility of introducing a broader program, including fish health, genetic and ecological considerations for Atlantic salmon introductions and transfers in northeast U.S.A. and the Atlantic coast of Canada, is currently being assessed by a bilateral Canada-U.S.A. working group under the North American Commission, North Atlantic Salmon Conservation Organization.

PROVINCIAL LEGISLATION AND POLICIES

Agencies administering fisheries in Canada have been encouraged to formulate supplemental regulations and implement policies related to fish health protection and control of diseases within the provinces. Examples of recent actions in this regard include:

- Ontario Ministry of Natural Resources (OMNR) has a comprehensive fish health protection policy, which describes procedures and protocols for controlling diseases in the provincial hatchery program. OMNR also has a policy that salmonid stocks imported from outside the province must be held first in quarantine facilities for up to 4 months post-hatching and checked for presence of communicable diseases before release. This is required even if stocks originate from facilities that are certified under the FHPR.
- The Province of Quebec has introduced the concept of zoning through regulation, allowing culture of certain salmonids in some regions of the province but not others. These regulations also require that permits be issued by provincial authorities for transportation of salmonids from one facility or river system to

another. The provincial government has a policy to allow importation of salmonids only if the stocks needed cannot be provided from within the provincial hatchery program.

- The Department of Fisheries and Oceans has developed guidelines related to intraprovincial salmonid movements within the provinces of Nova Scotia, New Brunswick and Prince Edward Island; the purpose of these guidelines is to prevent dissemination of furunculosis, enteric redmouth disease and BKD.

- The Department of Fisheries and Oceans has required that Atlantic salmon eggs imported to British Columbia be held in quarantine for 1 year to the smolt stage and be inspected regularly for communicable diseases.

These regulations and policies have been developed in response to fish health concerns that are specific to individual regions/provinces. In each case, they have further minimized fish health risks of importations permitted under the FHPR, or addressed intraprovincial concerns not covered by the national regulations.

Furthermore, with the rapid development of the aquaculture industry, alternative capability for fish health and disease diagnostic services is also being developed and encouraged by agencies concerned with regional development. These include diagnostic laboratories operated by provincial agencies (e.g. in New Brunswick, Quebec, Ontario and British Columbia), veterinary colleges in Ontario, Quebec and Prince Edward Island and private industry. While private sector participation in the fish health service field has been slow, opportunities for viable enterprises will grow as the number of fish farms and production levels increase. Private firms have developed vaccines which are licensed for production and sale in Canada and internationally. Other companies should shortly enter the market with test kits for quick identification of fish pathogens.

Programs for training and skill development in the fish health field are also expanding; educational programs in Canada fall within provincial jurisdiction. Technician training programs are established in colleges in New Brunswick, Quebec, Ontario and British Columbia. Course work covers the subjects of protection from, and control and eradication of, fish diseases. More intensive academic courses and opportunities for graduate studies in the fish health field are becoming available at universities, particularly at the veterinary colleges in Charlottetown (Prince Edward Island), St. Hyacinthe (Quebec) and Guelph (Ontario).

FUTURE DIRECTIONS

International and interprovincial exchange of cultivated species is increasing rapidly as fisheries managers develop new fisheries opportunities and aquaculturists try to acquire sufficient seedstock for their operations and seek to introduce new strains for broodstock development. Expectations are also changing, as are the technologies, public and professional awareness and standards of acceptability. New, more effective techniques for disease detection are emerging, drugs are being registered for control of fish diseases in aquaculture, technologies for quarantine facilities are improving and public demand for stringent fish health protection practices is increasing. Hence, the requirement for a broad, integrated program to protect the health of our fisheries has never been so important.

Canadians have been responsive to potential health risks to natural salmonid resources from increased transfers required for resource development and the expanding aquaculture industry. National regulations are being applied uniformly to minimize risks of introducing or disseminating fish disease agents through importation and interprovincial transfers of stock. Participation by federal and provincial government agencies and the private sector in regional fish health protection programs has enhanced national initiatives. Similarly, regulations and policies have been developed in some provinces to meet local needs and problems that were not addressed by the national regulations. Legislation is also in place to control industry-related hazards. The strong capability in all sectors to conduct R&D has resulted in legislation and policies, and technological innovation has resulted in development of new methods for detection, prevention, control and eradication of diseases. Improved education and training programs will also lead to greater selfsufficiency in the private sector for services such as disease diagnosis, prevention and control.

Fish Health Protection Regulations in Canada have been generally well received by public and private interests alike. Although the FHPR are considered to be rigorous, they clearly do not create non-tariff barriers to trade. Standards and procedures have been established that apply equally to importation from other countries and internal (interprovincial) transfers of salmonids, thus facilitating trade. There is no ban on transfers if the standards for fish health are met. No change in this stance is foreseen.

In spite of much progress and a credible research effort in Canada, there is no room for complacency. Fish diseases are still considered one of the major constraints in salmonid farming and the need for continued attention to fish health concerns should be reiterated and new initiatives considered. Administration of the Regulations has been and will continue to be reviewed on a regular basis, and changes have been made as new information and technologies have become available. However, changes to the Regulations can create problems for industry, which has tended to adapt the standards established under regulations as instruments of their business plans. A significant impact of the overall salmonid fish health protection program in Canada has been the perception by various interests that risks of exposure to diseases are being minimized. This has helped create a favorable climate for major investments in salmonid farming and supplementary industries.

Intraprovincial fish health protection measures can be expanded to new regions based on existing models, given the increased willingness of administrators to make decisions locally regarding conservation and protection of the natural resources, and the expanding data base related to these resources. Existing legislation and compliance protocols also need to be refined as new technologies are developed and the data base on fish diseases increases. For example, improved technologies for quarantine facilities are expected to facilitate development of guidelines for safer transfers of salmonid seedstock.

Fish health protection cannot be used as the sole basis for decisions that permit introductions and transfer of stocks, given the potential for genetic and ecological impacts of such transfers. Hence, legislation that incorporates assessment for all these factors needs to be developed and consolidated. A model is being examined in this regard under the North American Commission of the North Atlantic Salmon Conservation Organization and the Great Lakes Fishery Commission.

Finally, as part of the North American continent, Canada is likely to seek opportunities to collaborate with the U.S.A. in developing a continental approach towards importation of salmonids from other countries. This is seen as a most timely and appropriate initiative, and all are encouraged to work towards this end. Efforts have been made in the past to develop international agreements which would control introduction of communicable diseases through movement of eggs and fish (e.g. Food and Agriculture Organization in the 1970's), but the basis for an agreement between participating countries could not be reached. The Canadian government recognizes that participating in such an international agreement is a desirable objective, and would probably support initiatives towards this end. However, its participation would depend on the parallels and integration of an international agreement with Canadian regulations and policies. Continental concerns remain a higher priority.

SOME ASPECTS OF SELECTION IN SALMONID AQUACULTURE

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ABSTRACT

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Literature relative to the potentials for selection gains in salmonid aquaculture is reviewed in this paper. Estimates of heritability, genetic correlations, reproductive rate, generation interval, economic importance of traits and other factors are considered in the prediction of selection responses. Realized responses are considered in a small number of experiments where they have been documented for salmonids. Also, some reference is made to other species, both aquatic and terrestrial, where selection has been more extensively practised.

RÉSUMÉ

Friars, G. W., J. K. Bailey and K. A. Coombs. 1991. Some aspects of selection in salmonid aquaculture p. 85-92. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

On examine ici les documents existant sur les possibilités de gains par la sélection dans l'aquiculture des salmonidés, en envisageant les estimations d'héritabilité, les corrélations génétiques, le taux de reproduction, l'intervalle entre les générations, l'importance économique des traits caractéristiques et d'autres facteurs dans la prédiction des réponses à la sélection. On envisage aussi les réponses obtenues dans un petit nombre d'expériences, où elles se sont avérées valables pour les salmonidés. Enfin, on traite d'autres espèces, aquatiques et terrestres, parmi lesquelles la sélection est très répandue.

INTRODUCTION

The theory of quantitative genetics has been reviewed by several writers in this century, and textbooks by Lerner (1958) and Falconer (1981) have dealt with applications of this theory. Both of these books refer to works of Fisher (1918) on correlations between relatives, and of Wright (1921) pertaining to systems of mating. These two classical papers are fundamental to a discourse on selection and mating systems, two phenomena which must be considered together like "hand in glove" in a discussion of breeding programs.

CROSSING AND INBREEDING

The crossing of lines has been used to gain heterotic advantages, particularly in reproductive traits in poultry (Friars et al. 1963). This may, in some cases, merely represent a recovery of inbreeding depression and depend on the degree of inbreeding in the lines as in the experiment of Jui and Friars (1980). In fact, parr length and weight in Atlantic salmon showed essentially no heterotic effect in crosses of stocks of Atlantic salmon from different river systems (Friars et al. 1979). However, in a multiple trait study, Gjerde and Refstie (1984) found heterotic effects for some survival and growth traits but not others in diallel crosses of five strains of Atlantic salmon. Conversely, negative production effects were encountered when heterosis was observed for the incidence of precocious male parr in crosses of river stocks of Atlantic salmon (Glebe and Saunders 1986). In connection with crossing, the production of many nearly homozygous lines through gynogenesis or androgenesis may become practical, depending on the fertility and survival in such fish (Thorgaard 1986). The testing of large numbers of crosses of such partially homozygous lines could possibly allow the identification of superior combinations that might be repeated on a commercial basis.

Inbreeding may have some place in selection when heritability is low and where cycles of temporary intense inbreeding, followed by crossing among inbred families with a combination of individual plus family selection in each generation, yielded optimum theoretical gains (Dickerson and Lindhé 1977). However, the progress from selection was impeded in an upward direction in *Tribolium castaneum*, where selection gain was reduced with higher compared to lower levels of inbreeding over seven generations (Jui and Friars 1974). Also, inbreeding depression for survival and growth traits in rainbow trout has been observed (Gjerde et al. 1983; Kincaid 1983). Consequently, safeguards against inbreeding need to be considered in breeding programs.

The level of inbreeding increases with decreasing numbers of effective parents (Falconer 1981). Most frequently, problems are encountered through too few founding parents in fish populations. The effects of inbreeding are cumulative from one generation to the next. Therefore, the effective numbers of parents must be considered in each generation. Selection has a tendency to decrease the number of effective parents and consequently increases inbreeding, as noted in a comparison of the inbreeding coefficients between the control and the minimal inbreeding lines of Jui and Friars (1974). This effect is obtained because genes identical by descent have a higher probability of being paired through the union of gametes.

An approximation of the degree of inbreeding acquired in a single generation of random mating in a finite population can be obtained through the use of the formula:

$$\Delta F = 1/8N_m + 1/8N_f$$

where ΔF is the change in inbreeding, N_m is the number of male parents and N_f is the number of females used. Single-pair matings will tend to minimize inbreeding. For example, 30 parents represented by 15 males randomly mated to 15 females yield a ΔF of .017 per generation, whereas five males mated at random with 25 females results in a ΔF of 0.30. Refinements of this formula are needed for non-random mating or where unequal numbers of progeny per pair of parents are contributed to the breeding population of each generation. When pooled milt from two or more males is used in salmonids, disproportionate numbers of progeny are produced by respective males (Withler 1988). Therefore, attention to mating procedures is paramount in breeding programs.

Practical approaches to minimizing inbreeding, at least in the short term, can be implemented by such procedures as moving milt from one subpopulation to another (Fig. 1). This system ensures that matings between relatives, closer than first cousins, do not occur. The subpopulations could represent farms or blocks of cages within farms. Similar systems can be used with fewer generations required to complete the circuit (e.g. Kincaid 1977; Schom and Bailey 1986).

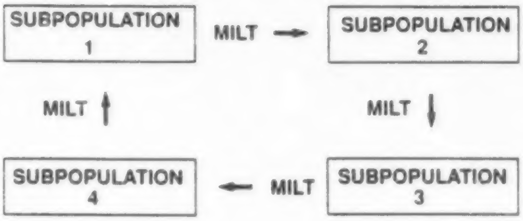

Fig. 1. Mating plan to reduce inbreeding where eggs are left in the same subpopulation (e.g. location) and milt is transferred each generation.

SELECTION IN TERRESTRIAL SPECIES

The process of artificial selection in plants and animals probably dates to the early days of domestication. The application of modern genetic and biometrical knowledge has greatly accelerated the rate of change from selection. Recent reviews of achieved and projected progress from selection have been documented for terrestrial animals by Smith (1988) and Ollivier (1988) and for plants by Schnell (1988). The use of selection practices in agricultural species is an important component of the strategies currently being used by animal and plant breeders.

POTENTIAL FOR SELECTION IN SALMONIDS

The coefficient of variation for many traits in fish is often greater than that in terrestrial animals (Gjedrem 1975). The data in Table 1 show high coefficients of variation for Atlantic salmon. The lower coefficients of variation connected with length, in contrast to weight measurements in Atlantic salmon, are interesting. The measurement error is usually lower for length than for weight. Additionally, under adverse conditions, length data can be procured more easily than weights. Hence, even with a lower coefficient of variation, length is often a more attractive measure of size than weight.

Table 1. Estimates of coefficients of variation for certain traits in SGRP strains.

Trait	Coefficient of variation (%)
Number of eggs per female	28.0
Egg volume per female at eyed stage	67.0
Number of parr per female	81.7
Weight - fry	31.7
parr	20.8
smolt	47.4
10 months in sea cages	30.1
Length - fry	10.2
parr	8.4
smolt	36.5
10 months in sea cages	8.0

(Data from Salmon Genetics Research Program Annual Report 1986/87. Atlantic Salmon Federation, St. Andrews, N. B., E0G 2X0.)

Evidence suggesting that the extensive variance of several traits in salmonids is heritable has been presented in the review papers of Gjedrem (1983) and Gjerde (1986). The reasonably high heritability estimates for traits such as size at a given age, augur well for expected selection response. However, some of the survivability and carcass quality traits are less heritable and will require sophisticated selection schemes to yield responses.

SELECTION GOALS

The establishment of selection goals is important at the start of any breeding project. In Atlantic salmon and many other species, the current demand appears to be focused on improved growth rate. Certain physiological phenomena, such as sexual maturation of male parr, age at smoltification and age at sexual maturation in salt water, tend to decrease growth. Correlations between freshwater and saltwater growth weaken as the fish are raised in salt water for more extended periods of time (Friars et al. 1988). Hence, multiple objective selection for growth may be required, particularly where profits are of concern to both hatchery and grow-out operations in a non-integrated industry. Other traits such as carcass quality and disease resistance may ultimately be involved in selection programs.

The preference for some grilse in the marketed fish is increasing in certain parts of the world since there is evidence that grilse grow faster than salmon contemporaries up to the time of sexual maturation (Bailey and Friars 1987). However, the preference in the Bay of Fundy sea-cage industry appears to discriminate against grilse since marketing is done at about 4 kg live weight after about 18-20 mo of growth in salt water. Such changes in demand need to be anticipated as far in advance as possible in order to establish or modify long-term selection goals.

SYSTEMS OF SELECTION

Simple mass selection for grilse length yielded a positive response in an experiment reported later in this paper. However, family performance, together with the performance of individuals within families, may need to be considered in many instances. The within-family variation may be particularly important since common environmental factors, such as tank effects, are often confounded with families. The high reproductive rate in many aquatic species allows the application of intense selection within families. For example, in the case of full sib families, one-half of the total additive variance is within families. Combinations of within- and between-family information can be used when environmental effects are not confounded with families, where all families are reared in the same sea cage and, presumably, are not seriously affected by previous environmental effects such as fry-tank density. Theory developed by Lush (1947) indicates that such a combination of information should always yield more efficient response to selection than that expected on the basis of individual merit alone, particularly in the case of traits with low heritability. This expectation was realized in a selection experiment with *Tribolium castaneum* by McLeod and Friars (1986), although genetic gain from family selection was frequently below expectation.

Variance between replicates in selection experiments causes concern (Fairfull et al. 1977; Bohn et al. 1983; Patterson et al. 1983). Variation in response can be at least partially offset by increasing effective population size (Doyle and Talbot 1986). These results imply that selection experiments should be based on large populations that preferably involve replication.

In addition to considering multiple sources of information from individuals and relatives for a single trait, multiple traits may need to be considered. Selection indices or other formulated procedures, combining information on multiple traits as well as that from relatives, are frequently used. Quadratic indices may be more efficient than linear combinations where traits such as survival and growth rate may need to be combined. In this case, a single measure such as biomass per family may be useful (Fairfull et al. 1977). In order to achieve appreciable genetic gains in individual traits, the number of traits considered in multiple objective selection should be kept as low as possible.

The relative economic weights assigned to traits needs to be considered in the formulation of selection indices and, in many cases, this information may not yet be available in specific areas of aquaculture. Economic weights must ally closely with selection goals.

GENERATION INTERVAL

The generation interval in many salmonids is long compared to that of some agricultural species. In Atlantic salmon, depending on whether sexual maturity of the parents is realized after they have been through one sea-winter (grilse) or two or more sea-winters (salmon), the generation interval is 3 or 4 or more yr. In contrast, a generation of broiler chickens can be produced in 8-9 mo. Thus, the genetic gain per year would be expected to be smaller in Atlantic salmon. Some of this disadvantage can be offset by the higher selection intensities that can be achieved in salmon because they produce larger numbers of offspring per parent.

GENOTYPE X ENVIRONMENT INTERACTION

Different sets of genes may be required for different environments. The results of McKay et al. (1984) demonstrated a significant re-ranking of families for growth in 7°C and 15°C water. Similarly, strains within species involving lake trout, brook trout and rainbow trout responded differently when respective samples of each were reared in 8°C and 16°C water (Sadler et al. 1986). Other cases of family X treatment interaction have been observed (e.g. Austreng and Refstie 1979; Hanke 1988). These results suggest that, as in the case of agricultural species, selection should be carried out in environments similar to those in which the commercial progeny is to perform.

SELECTION EXPERIMENT

There have not been any long-term selection experiments with control populations in salmonids as indicated in the review paper of Gjerde (1986). In contrast, such experiments have been conducted for 21 generations in poultry (Gowe et al. 1973) and 106 generations in a pilot organism, *Tribolium castaneum*, (Enfield 1976). Data on short-term selection experiments in fish are, therefore, pertinent at this time.

This section documents a single-generation, controlled-selection experiment for grilse fork length in Atlantic salmon conducted in the Salmon Genetics Research Program. In November 1985, a control line was established with no more than one sire and one dam sampled at random from individual full-sib families in a population of approximately 1400 individuals maturing as grilse. Forty-five single-pair matings were used to form a control line. Mass selection for fork length was applied to the remainder of the population. Forty-eight single-pair matings were established in the select line. Full-sib matings were avoided in both the select and control lines. The mean lengths were 59.0 cm for the control line and 65.7 cm for the select line, yielding a selection differential of 1.52 standard deviations. The numbers of families that survived to 70 wk in seawater were 42 and 39 for the control and select lines, respectively.

Differentials in egg numbers per female and survival to the fry stage yielded 1270 and 2135 progeny for the control and select lines, respectively (Table 2). Each family had been reared to that stage in separate 1.1-m tanks. The linear regressions of fry length and weight on numbers per tank were negative and not significantly different between the control and select lines. Hence, a covariance correction for numbers per tank was applied to the fry weight and length data. The control fry were larger than the selects in the uncorrected data, whereas those differences were reversed when corrected for the number per tank. Hence, correlated selection gains, although not significant, were apparent at the fry stage, but such differences became confounded with the higher densities of larger families in fry tanks.

When transferred to outdoors at about 13 wk after first feeding, the numbers per rearing tank were balanced. This was accomplished by matching families that balanced with respect to numbers per family. All control individuals were saved. A random sample of 300 individuals from three select families was also placed in each outside tank. Three control and three select families were represented in each tank. Duplicate tanks for each set of six families were used. An accurate method of separating the control and select lines was used, where an adipose fin clip on the select families vs no adipose fin clip on the controls displayed no apparent regeneration. On the contrary, regeneration of pelvic fin clips used to separate the three families within each line-tank combination presented problems in accurate separation of families within lines.

The proportion of apparent smolts determined by a minimum length of 13 cm about 2-3 mo before transfer from fresh to salt water was higher in the select than in the control line (Table 3). However, this difference is 2.28% when the analysis is based on family means in tanks in contrast to 6.90% on the basis of line means in tanks. This occurred because some control families with high numbers of progeny had low rates of smoltification. Similarly, positive correlated responses to selection for grilse fork length were apparent in both parr and smolt fork length. The incidence of males in parr was higher than in smolts (Table 2), although this difference was not significant ($P < 0.05$). The increased incidence of male parr in the control compared to the select line may be associated with precocious sexual maturation of males that possibly interferes with smoltification.

Table 2. Percent smolts and mean fork lengths of Atlantic salmon smolt and parr.

Trait	Control	Select
Percent smolt[a]		
Tank model	62.20	69.10 *
Family model	67.23	69.51
Fork length (cm)		
Smolt[b]	16.21	16.48 **
Parr	11.05	11.15 **
Percentage of male parr[c]	75.6	63.2
Percentage of male smolts	42.8	44.3

*Difference between control and select significant ($p < 0.05$).

**Difference between control and select significant ($p < 0.01$).

[a] The family represented an additional effect in the model but was deleted in the tank model.

[b] Presumptive smolts based on a fork length of 13 cm or greater in February prior to placement in sea cages in May.

[c] The percentage of male parr and smolts was based on 15 parr and 15 smolts in each of 22 control and 22 select families.

(Data from G. W. Friars, J. K. Bailey and K. A. Coombs, submitted to the Third International Symposium on Genetics in Aquaculture and the SGRP Annual Report 1986/87.)

Table 3. Least square mean fork lengths (cm) of Atlantic salmon reared in sea cages.

Line	Weeks in seawater			
	13	27	54	70
Control	28.82	44.20	53.80	66.65
Select*	29.31	45.35	55.09	68.49

*Select line significantly larger than the control ($p < 0.01$) at all ages.

(Data from G. W. Friars, J. K. Bailey and K. A. Coombs, submitted to the Third International Symposium on Genetic Aquaculture.)

Smolts from each of the families were evenly split between two sea cages in May of 1987. The mean fork lengths of the control and select lines at different stages of growth in seawater are presented in Table 3. The realized response reached 1.84 cm by 70 wk in seawater, just prior to sexual maturation as grilse. This represents a realized heritability of .27, indicating that response to selection at a given age can be useful. Using a weight-length regression from other data, the estimated realized weight gain was .26 kg. This represents a substantial economic gain in an industry producing large numbers of fish.

OVERVIEW

The amount of unexploited genetic variation, the high reproductive rate and the high economic returns are some of the factors which are favorable for genetic gains in salmonids and other species used in aquaculture.

REFERENCES

Austreng, E., and T. Refstie. 1979. Effect of varying dietary protein level in different families of rainbow trout. Aquaculture 18: 145-156.

Bailey, J. K., and G. W. Friars. 1987. Grilse versus salmon in sea cages. Salmon Genet. Res. Prog. Ann. Rep. 1986/87:13-15, Atlantic Salmon Federation, St. Andrews, N. B., Can.

Bohn, G. I., G. W. Friars, and I. McMillan. 1983. The variance of response to selection in *Tribolium castaneum.* Can. J. Genet. Cytol. 25: 44-46.

Dickerson, G. E., and N. B. H. Lindhé. 1977. Potential uses of inbreeding to increase selection response, p. 323-342. In E. Pollak, O. Kempthorne and T.B. Bailey, Jr. (ed.) Proc. Int. Conf. Quant. Gen. The Iowa State Univ. Press, Ames, Iowa.

Doyle, R. W., and A. J. Talbot. 1986. Effective population size and selection in variable aquaculture stocks. Aquaculture 57: 27-35.

Enfield, F. O. 1976. Selection experiments in *Tribolium* designed to look at gene action issues, p. 177-190. In E. Pollak, O. Kempthorne and T.B. Bailey, Jr. (ed.) Proc. Int. Conf. Quant. Gen. The Iowa State Univ. Press, Ames, Iowa.

Fairfull, R. W., G. W. Friars, and J. W. Wilton. 1977. An empirical comparison of selection methods for the improvement of biomass. Theoret. Appl. Genet. 50: 193-198.

Falconer, D. S. 1981. Introduction to quantitative genetics, 2nd Edition. Longman, London and New York. 340 + vii p.

Fisher, R. A. 1918. The correlation between relatives on the supposition of Mendelian inheritance. Trans. Roy. Soc. Edinburgh 52: 399-433.

Friars, G. W., J. K. Bailey, and K. A. Coombs. 1988. Correlations between freshwater and saltwater growth traits in Atlantic salmon. Bull. Aquacult. Assoc. Can. 88-4: 13-15.

Friars, G. W., J. K. Bailey, and R. L. Saunders. 1979. Considerations of a method of analyzing diallel crosses of Atlantic salmon. Can. J. Genet. Cytol. 21: 121-128.

Friars, G. W., F. N. Jerome, L. T. Weeden, and G. C. Ashton. 1963. Body weights and reproduction traits of two strains and reciprocal crosses of broad breasted bronze turkeys. Poul. Sci. 42: 935-940.

Gjedrem, T. 1975. Possibilities for genetic gain in salmonids. Aquaculture 6: 23-29.

Gjedrem, T. 1983. Genetic variation in quantitative traits and selective breeding in fish and shellfish. Aquaculture 33: 51-72.

Gjerde, B. 1986. Growth and reproduction in fish and shellfish. Aquaculture 57: 37-55.

Gjerde, B., and T. Refstie. 1984. Complete diallel cross between five strains of Atlantic salmon. Livestock Prod. Sci. 11: 207-226.

Gjerde, G., K. Gunnes, and T. Gjedrem. 1983. Effect of inbreeding on survival and growth in rainbow trout. Aquaculture 34: 327-332.

Glebe, B. D., and R. L. Saunders. 1986. Genetic factors in sexual maturity of cultured Atlantic salmon (*Salmo salar*) parr and adults reared in sea cages. In D. J. Meerburgh (ed.) Salmonid age at maturity. Can. Spec. Publ. Fish. Aquat. Sci. 89: 24-29.

Gowe, R. S., W. E. Lentz, and J. H. Strain. 1973. Long-term selection for egg production in several strains of white leghorns: performance of selected and control strains including genetic parameters of two control strains. 4th Eur. Poult. Conf., London, p. 225-245.

Hanke, A. R. 1988. Genotype X photoperiod interaction of growth of underyearling Atlantic salmon parr (*Salmo salar*). M.Sc. Thesis, Univ. of New Brunswick, Saint John, N.B., Canada.

Jui, P. Y., and G. W. Friars. 1974. Two-way selection on pupal weight with different degrees of inbreeding in *Tribolium castaneum*. Can. J. Genet. Cytol. 16: 765-775.

Jui, P. Y., and G. W. Friars. 1980. Performance of crosses of selected lines of *Tribolium castaneum*. Can. J. Genet. Cytol. 22: 129-136.

Kincaid, H. L. 1977. Rotational line crossing: an approach to the reduction of inbreeding accumulation in trout broodstocks. Prog. Fish-Cult. 39: 179-181.

Kincaid, H. L. 1983. Inbreeding in fish populations used for aquaculture. Aquaculture 33: 215-227.

Lerner, I. M. 1958. The genetic basis of selection. John Wiley and Sons, New York and London, 398 + xvi p.

Lush, J. L. 1947. Family merit and individual merit as bases for selection. Am. Nat. 81: 241-261, 362-379.

McKay, L. R., G. W. Friars, and P. E. Ihssen. 1984. Genotype X temperature interactions for growth of rainbow trout. Aquaculture 41: 131-140.

McLeod, D. L., and G. W. Friars. 1986. A comparison of individual, family and index selection methods in *Tribolium castaneum*. Can. J. Genet. Cytol. 28: 301-305.

Ollivier, L. 1988. Current principles and future prospects in selection of farm animals, p. 438-450. In B. S. Weir, E. J. Eisen, M. M. Goodman and G. Namkoong (ed.) Proc. 2nd Int'l. Conf. Quant. Gen. Sinauer Assoc., Inc. Publ., Sanderland, Mass., U.S.A.

Patterson, D. L., G. W. Friars, and I. McMillan. 1983. Effects of parental age and sampling method on response to index selection in *Tribolium castaneum*. Can. J. Genet. Cytol. 25: 47-52.

Salder, S. E., G. W. Friars, and P. E. Ihssen. 1986. The influence of temperature and genotype on the growth rate of hatchery-reared salmonids. Can. J. Anim. Sci. 66: 599-606.

Schnell, F. W. 1988. Quantitative genetics in crop improvement, p. 462-464. In B. S. Weir, E. J. Eisen, M. M. Goodman and G. Namkoong (ed.) Proc. 2nd Int'l. Conf. Quant. Gen. Sinauer Assoc., Inc. Publ., Sanderland, Mass., U.S.A.

Schom, C. B., and J. K. Bailey. 1986. Selective breeding and line crossing to reduce inbreeding. Prog. Fish-Cult. 48: 57-60.

Smith, C. 1988. Potential for animal breeding current and future, p. 150-160. In B. S. Weir, E. J. Eisen, M. M. Goodman and G. Namkoong (ed.) Proc. 2nd Int'l. Conf. Quant. Gen. Sinauer Assoc., Inc. Publ., Sanderland, Mass., U.S.A.

Thorgaard, G. H. 1986. Ploidy manipulation and performance. Aquaculture 57: 57-64.

Withler, R. E. 1988. Genetic consequences of fertilizing chinook salmon (*Oncorhynchus tshawytscha*) eggs with pooled milt. Aquaculture 68: 15-25.

Wright, S. 1921. Systems of mating. Genetics 6: 111-178.

BROODSTOCK DEVELOPMENT FOR NORWEGIAN SALMONID AQUACULTURE

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ABSTRACT

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Norwegian salmonid aquaculture had its real start around 1965 after several trials and failures during the previous hundred years. The first successful production was based on rainbow trout imported as eggs from Denmark, and the import of rainbow trout eggs lasted for many years. The European model of producing pan-size rainbow trout never became common in Norway, and fish farming became an industry only when the pioneers started to produce larger rainbow trout (1-3 kg) commonly with the on-growing phase in seawater.

Farming of Atlantic salmon started in the late 1960's by collecting eggs from spawners caught in rivers and coastal areas. The rapid development of the industry and plans for genetic improvement by selective breeding soon made it necessary to use farmed salmon for broodstock. The use of wild-caught salmon for broodstock became insignificant after a few years. The survival rate of eggs from farmed parent fish is more variable and on the average lower than for the eggs of wild salmon. Much effort has been placed in improvement of the egg quality of farmed salmon, and the situation is acceptable now.

Studies of genetic variation in productive traits were started by two governmental institutions in 1971. It soon became evident that the broodstocks used in Norwegian fish farming are of very variable quality with respect to genetic constitution. Selection and measurement of genetic gain were carried out from the second generation of the experimental fish. The more practical aspects of the selection work were taken over by the fish farmers associations in 1985, while the governmental institutions still conduct experiments on genetic control of "new" production traits, genetic/environmental interaction and other aspects for adjustment of the practical genetic program.

Mass selection programs conducted by the individual fish farming companies especially, are concerned with growth rate and age at first sexual maturity. The results of such selection are difficult to evaluate because of the lack of unselected controls, but there is reason to believe that some genetic gain has been obtained. Also, semi-natural selection due to adaptation to fish farming conditions seems to be of some importance.

Chromosome engineering (triploidy, gynogenesis, sex reversal) is carried out on an experimental basis, and will possibly soon be applied in practical fish farming. Gene technology is still on an experimental basis, but there is much optimism in obtaining genetic improvement of fish growth rate and disease resistance through gene technology.

Interaction between natural salmon populations and farmed populations has caused considerable concern in recent years. Escapement of farmed salmon of unknown origin and usually with changed genotypes due to selective breeding may cause erradiation of the natural interpopulation variations which are supposed to be very important for local river adaptation of the natural salmon. Different initiatives are

being taken to protect the natural salmon in genetic respects and to prevent the spread of diseases. For the same reasons, only broodstocks from the river in question are normally allowed to be used for enhancement of natural salmon stocks.

RÉSUMÉ

Nævdal, G. 1991. Broodstock development for Norwegian salmonid aquaculture, p. 93-106. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

La salmoniculture n'a commencé en Norvège qu'aux environs de 1965, après plusieurs essais et échecs au cours du siècle précèdent. Les premiers succès ont été obtenus avec de la truite arc-en-ciel importée du Danemark sous forme d'oeufs. Cette importation d'oeufs s'est poursuivie longtemps. Contrairement au reste de l'Europe, la Norvège ne s'est jamais orientée vers la production de truites de petite taille (de 20 à 25 cm). La pisciculture ne s'y est donc implantée que lorsque les pionniers commencèrent à produire des truites arc-en-ciel plus grosses (de 1 à 3 kg), dont le grossissement s'effectuait habituellement en eau de mer.

La pisciculture du saumon de l'Atlantique a débuté à la fin des années 1960, par le prélèvement d'oeufs sur des géniteurs capturés dans les rivières et les eaux côtières. Le développement rapide de cette industrie et les plans d'amélioration génétique par l'élevage sélectif obligérent bientôt les pisciculteurs à utiliser des saumons d'élevage comme géniteurs. Aussi, cessa-t-on de recourir aux géniteurs sauvages après quelques années. Le taux de survie des oeufs de saumon d'élevage est plus variable et en moyenne inférieur à celui des oeufs de saumon sauvage. On a déployé beaucoup d'efforts pour améliorer la qualité des oeufs de saumon d'élevage, qui est maintenant acceptable.

Deux établissements gouvernementaux entreprirent, en 1971, d'étudier la variation génétique des caractères productifs. On constata rapidement que les géniteurs utilisés par les pisciculteurs norvégiens sont de qualité très variable en ce qui a trait à la constitution génétique. On a eu recours à la sélection et à la mesure de gain génétique à compter de la deuxième génération de poissons expérimentaux. Les associations de pisciculteurs assument les aspects les plus concrets du travail de sélection depuis 1985, tandis que les établissements gouvernementaux continuent d'effectuer des expériences sur la régulation génétique de "nouveaux" caractères, sur l'interaction enre la génétique et le milieu et sur d'autres facteurs, dans le but d'améliorer les applications pratiques du programme de génétique.

Les programmes de sélection massale, mis en oeuvre surtout par certaines entreprises piscicoles, portent sur le taux de croissance et l'âge à l'arrivée de la maturité sexuelle. Il est difficile d'évaluer les résultats de ce genre de sélection en raison de l'absence de contrôles hors sélection, mais on a de bonne raison de croire qu'il est profitable. Par ailleurs, la sélection semi-naturelle due à l'adaptation aux conditions d'élevage semble jouer un certain rôle.

On procède, à titre expérimental, à des manipulations chromosomiques (triploïdie, gynogénèse, renversement du sexe), qui pourraient être appliquées bientôt dans les exploitations piscicoles. La technologie génétique demeure au stade expérimental, mais on est confiant de pouvoir obtenir grâce à elle une amélioration génétique du taux de croissance et de la résistance aux maladies.

On s'est beaucoup préoccupé de l'interaction entre les populations de saumons naturels et celles de saumons d'élevage ces dernières années. Il est possible que les échappées de saumons d'élevage d'origine inconnue, dont les génotypes ont généralement été modifiés par l'élevage sélectif, entraîne l'élimination des variations naturelles entre les populations, supposées être très importantes pour l'adaptation du saumon naturel aux rivières locales. Différentes mesures sont prises pour protéger l'intégrité génétique du saumon naturel et empêcher la propagation des maladies. Pour ces raisons, seuls les stocks de géniteurs d'une rivière donnée servent normalement à améliorer les stocks de saumon de cette rivière.

INTRODUCTION

Farming of salmonids in Norway has been one of the most successful industries ever recorded in our country. With a start from nearly nothing in the 1960's, the production has increased to around 74,000 tons in 1988, consisting of 7000 tons rainbow trout, 67,000 tons of Atlantic salmon and small quantities of other species, i.e. Arctic charr.

Around 1870, the first known fish-rearing experiments were started in Norway. Sea trout, *Salmo trutta*, Atlantic salmon, *S. salar*, and also hybrids between sea trout and Arctic charr, *Salvelinus alpinus*, were reared in sea enclosures. However, probably for technical reasons, these pioneer fish farms yielded poor profit and were soon discontinued. Similarly, rearing of rainbow trout, *S. gairdneri*, practised around 1910, also lasted only a few years.

Interest in salmonid rearing was reawakened in the 1950's. Although many of the fish farms again showed rather poor results and most of them were discontinued after a few years, the current fish-farming industry developed during the late 1960's. Its success seems to be closely connected with the developments of new types of sea enclosures and simple types of floating pens in seawater. Such techniques reduce the investment cost and provide greater security than, for instance, concrete reservoirs or excavated ponds into which seawater is pumped.

During the early years, the main emphasis was placed on rainbow trout. Production of Atlantic salmon subsequently increased faster than that of rainbow trout and surpassed it in 1976. The quantities produced of salmonid species other than Atlantic salmon and rainbow trout are still quite small although some potentialities are seen concerning Arctic charr.

Releases of unfed fry, start-fed fry, parr and smolt of brown (sea) trout and salmon for enhancement of natural populations have been, and still are, important activities locally and as compensation for reduced natural recruitment due to river regulation and acidification. Sea ranching in Norway is still performed on an experimental scale only, but judging from the rather encouraging results of the later experiment, such activities may be more important in the near future (Hansen and Jonsson 1988).

In the present report, the history and status of broodstocks for salmonid culture are described. Research and development on genetic variation and genetic improvement are reviewed and discussed with main emphasis on the status and further development of intensive fish farming. The broodstock situation for enhancement and sea ranching is also considered, and the relation between culture and natural populations is dealt with briefly.

ORIGIN OF BROODSTOCK FOR THE FISH FARMING INDUSTRY

Rainbow trout eggs for intensive fish farming were imported from Denmark, and such imports lasted for many years, well into the 1970's. In Norway, the production of "pan-size" rainbow trout never became common. Instead, a bigger rainbow trout of 2-5 kg is produced mainly with the on-growing stage in salt or brackish water. Although not well documented, it seems evident that an adaptation to such production has taken place, probably as a result of seminatural selection in the fish farming environment. At the moment, about 4 million 50- to 100-g rainbow trout are transferred each year to the food fish farms. With a mortality of 50% from the egg stages, this indicates an egg production of 1000-1200 L. The genetic improvement program (see below) also includes rainbow trout, but the activity on this species is low compared to salmon.

When the farming of Atlantic salmon started around 1970, rather small quantities of eggs were taken from wild-caught salmon. Some of the pioneer fish farms were allowed to fish for broodstock in some fjords outside the fishing season, or eggs were bought from local sport fisherman's associations or other groups carrying out enhancement work on natural salmon populations. Two research institutions (Agricultural University of Norway, Ås, and Institute of Marine Research, Bergen) started work on quantitative genetics (see below) by collecting fertilized eggs from a limited number of parent fish from about 20 rivers in the years 1971-74, and occasionally later.

It is well known (Berg 1964) that salmon from different populations differ widely in size and age at maturation, i.e. in important productive traits for intensive fish farming. In some rivers, large multi-sea-winter salmon are found, while other rivers mainly or predominantly contain "grilse" (one-sea-winter salmon). Several rivers are also known to contain both large and small salmon. Although the demand may differ somewhat from year to year, by and large, the price of salmon increases with size. It is therefore important to produce as large a fish as possible within a reasonable time, and it is also important that the age at first sexual maturity is high enough to prevent decreased growth rate and deteriorating flesh quality due to the maturation process. Thus, it was expected that the genetic "value" of the natural salmon would be very variable between and within river populations when used for intensive fish farming. This is the basic theory for the genetic improvement programs carried out by research institutions and the Fish Farmers Association, as well as for the mass selection carried out by the individual fish farmers.

Collection of eggs from wild-caught salmon soon became insufficient for the growing fish farming industry, and farmed fish had to be used for broodstock. The egg quality of the farmed fish caused problems the first years and, even at the present time, the survival of eggs from farmed fish is lower and more variable on the average than survival of eggs from wild-caught salmon.

The total demand for salmon eggs today is about 40,000 L.

Arctic charr is raised in limited numbers by research stations and some commercial fish farms. Until now, eggs are collected from wild-caught anadromous (northern Norway) or lacustrine populations. Similar to salmon, the productive traits of charr are greatly variable and thus genetic improvement programs will have to be started if Arctic charr is to become a candidate species for intensive aquaculture. Eggs have been collected from natural populations to meet the limited egg requirements for experiments on brown or sea trout and species hybrids carried out by research stations (Refstie and Gjedrem 1975; Foldøy 1977; Gjedrem and Gunnes 1978).

GENETIC VARIATION IN PRODUCTIVE TRAITS

The philosophy behind the selective breeding experiments which were started in Norway was that in the domestication of wild species, the greater part of the natural competition, and hence the natural selection, is eliminated. Instead, there should be room for artificial selection based on utilization of variations in productive traits. Such variations are supposed to exist within and between natural populations but, in nature, the selection goals are survival traits, not production traits in our sense of the word. Thus, by eliminating the natural selection for survival and taking care of the whole life cycle of the fish, artificial selection for improved production will be possible.

The first approximation of such studies will be to investigate the genetic variation in representative basic populations, to estimate genetic parameters and then to plan more extensive genetic selection programs. Atlantic salmon was a "true" wild species around 1970, and a reasonable start was made to collect fertilized eggs from a number of natural populations and raise them under identical and representative fish farming conditions. Rainbow trout was a culture species before the Norwegian fish farming industry started, but this industry is very different from the Danish or German pan-size fish production from which the material originated. Thus, it was supposed that still considerable variation existed which could be utilized in our kind of culture. Breeding programs to study this genetic variation were started nearly simultaneously by two research institutions: the Agricultural University of Norway, Ås (later Institute for Aquaculture Research or AKVAFORSK), and the Institute of Marine Research, Bergen. The institutions built up research stations to conduct the rearing experiment at Sunndalsøra (in mid-Norway) and at Matre (abouut 70 km north of Bergen), respectively. The experiments at Sunndalsøra were preceded by preliminary experiments on rainbow trout at Dal, north of Oslo.

At both institutions, eggs were sampled from a number of natural populations and from the rather scarce material which existed in intensive fish farms in 1971. Usually a 2 x 2 factorial design was used based on two parent fish from each sex from each river population.

Later, a simpler model was applied by fertilizing the egg batches from three or more females by sperm from one male. The latter model allows a simpler data treatment, but does not allow for calculating genetic parameters based on maternal half sibs. Alternative models were used for specific purposes.

Gjedrem (1976) summarized the possibilities of genetic gain in salmonids, stressing the importance of well defined breeding goals. He also gave an account of actual and potential goals based on preliminary results for four parameters: selection differential (i), heritability (h^2), phenotypic standard deviation (σ_p) and generation interval (L), which are important for response to selection for the most important traits, i.e.

$$\Delta G = \frac{ih^2 \sigma_p}{L}$$

Phenotypic variation and heritability estimates are dealt with in several papers, most of which are reviewed by Gjedrem (1983) and Gjerde (1986).

Concerning growth rate, heritability factors from zero to around 0.5 were estimated for Atlantic salmon and rainbow trout, and also strain differences were found for Atlantic salmon. There was a general trend, although not consistent, of lower heritability factors for growth rate in the earlier than in later stages of the life cycle (Refstie and Steine 1978). Gjerde (1986) stressed the importance of calculating the genetic parameters for selection purposes close to the marketing time which, for the smolt producer, will be at the time of saltwater transfer, while for the food fish producer it will be at the time of slaughtering. Phenotypic and genetic correlations between the growth rate in these two periods are poorly known (Gjerde 1986), although limited data on individually tagged fish showed a positive, although not very strong, correlation between smolt size and size at later stages for Atlantic salmon (Nævdal et al. 1978; Skilbrei 1985), and between size at different stages in the life cycle for rainbow trout (Tofteberg and Hansen 1987).

The trait "age at maturity" has been subjected to intensive studies because of its impact on growth rate and flesh quality. The results were reviewed by Gjedrem (1983) and Gjerde (1986). Considerable variations were found between and within strains in a given environment. However, the results were not always consistent, and this fact is reflected in the very different estimates of heritability factors varying from zero to 0.84. Evidently, the variation in age at maturity also depends on environmental factors, discussed by Nævdal (1983) and clearly demonstrated by Hansen et al. (1988) who found large differences in incidences of two-winter salmon as compared to later maturation, when representatives of the same families were raised in different environments (fish farms) from southern and northern Norway. Thus, "age at maturity" is evidently determined by both environmental and genetic factors and, possibly, by genetic/environmental interaction. Phenotypic and genotypic correlations between traits are discussed below.

Precocious maturation also seems to be genetically determined although Gjerde (1984) found strong evidence for independent heritage of parr and "normal" maturation. It is still not clear what significance this trait has on productive traits.

Other carcass traits have been dealt with by Gjerde and Gjedrem (1984). Torrissen and Nævdal (1984, 1988) found clear effects of genetic factors in the ability to deposit carotenoids in the flesh in rainbow trout. There were similar strong indications of this effect in Atlantic salmon. In a series of papers (Gjerde 1987, 1989; Gjerde and Martens 1987; Gjerde and Schaeffer 1989) results were reported from analyses of the carcass compositions of rainbow trout by using an infrared reflectance spectroscopy method and computerized tomography. It was concluded that the genetic influences on such traits as body shape, belly thickness and fat content are significant and these traits could be included in large-scale breeding programs.

Genetically determined differences in disease resistance have been much debated, and disease resistance would be a valuable trait to be included in breeding programs if reasonably good methods of measurement could be obtained. Gjedrem and Aulstad (1974) found strain differences in resistance to vibrio disease in Atlantic salmon, and Gjedrem and Gjerde

(1986) found variation between families of Atlantic salmon in survival (from 60-96%) after an attack of cold water vibriosis.

Phenotypic and genetic correlations between productive traits have been dealt with by Gjerde and Gjedrem (1984). They concluded that high correlations existed between ungutted and gutted weights, weights/lengths and meatiness. Concerning the important traits of growth rate and "age at maturity," the situation is unclear. A careful conclusion seems to be that a low, but significant, genetic correlation exists between growth rate and "age at maturity," implying that selection for a higher growth rate may result in an unwanted lower "age at maturity." The interaction between growth rate and "age at maturity" is, however, complicated, and commencement of the maturation process evidently gives rise to improved growth rate (Nævdal et al. 1983; Hansen et al. 1988), while later in the maturity process, the growth rate is decreased and eventually stopped. Thus, the interpretation of growth rate measurements is greatly dependent in the fishes' stage of maturity.

A general conclusion of this chapter is that the rainbow trout and Atlantic salmon used in the Norwegian fish farming industry are highly variable concerning the genetics of productive traits. Genetic improvement by selection seems very promising, at least concerning growth rate and "age at maturity."

THE FISH FARMERS' GENETIC IMPROVEMENT PROGRAM

Selection experiments based upon the above genetic treatments have given an improved growth rate of 3.6 and 4.3% per year for Atlantic salmon and rainbow trout, respectively (Anon. 1987; Gjerde 1983). Such promising results and the estimated genetic parameters were the prime cause of the establishment of the Norwegian Fish Farmers' Breeding Center A/S in 1986. The objectives of this selection program and its organization are described by Anon. (1988) and Gunnes (1987). The fish farming industry owns the centre through the following organizations: Norwegian Fish Farmers' Sales Association, Norwegian Fish Farmers' Association and Norwegian Smolt Producers Association. These organizations appoint a council which is in charge of the management of the centre. Fish farmers constitute the majority of the council, and the Institute of Marine Research and the Institute of Agriculture Research have one representative each.

At the Breeding Centre in Kyrksæterøra, about 150 families of each species are tested for production performance each year. These families are also tested at five test stations located along the coast. Based upon the results, a combined family and individual selection is performed. Selection intensity of about two standard deviations is practiced. This is considered to be high enough for a reasonably high expectancy of genetic gain but should not result in any significant inbreeding.

The model for the spread of the improved genetic materials is shown in Fig. 1.

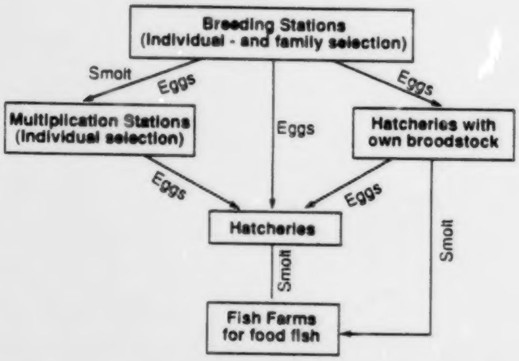

Fig. 1. Spreading of genetic gain under the fish farmers' genetic improvement program (Gunnes 1987).

Fry or smolt from the breeding centre are distributed to 14 affiliated broodstock multiplying stations along the coastline from Stavanger to Finnmark. Here the fish are kept until sexually mature. Mass selection is then practiced based on individual growth rate performance. Fertilized eggs from the selected broodstock are sold to smolt producers which in turn sell them as smolt to fish farmers. In this way, genetically improved fish are readily made available to the fish farming industry. In addition, there is a possibility to deliver eggs or milt directly from the Breeding Centre to smolt producers.

The total capacity at the Breeding Centre and the multiplying stations is sufficiently high to supply the whole fish farming industry with breeding material, but several smolt producers still keep their own broodstock.

The multiplying station, and especially the Breeding Centre, are subjected to very comprehensive health controls to prevent the spread of disease agents within the breeding material.

DOMESTICATION AND MASS SELECTION

In addition to the systematic selection programs initiated by research institutes and later continued by the fish farmers' associations, several private fish farms or companies have carried out mass selection for improved growth rate and late maturation. The effect of such selection is difficult to evaluate because no unselected controls exist. However, mass selection is considered to have a considerable affect on the production capacity of the fish. This is especially evident for rainbow trout. One of the pioneer fish farmers started mass selection against early maturity from the very beginning of his activity in 1964, and at present his strain contains very few fish maturing during their second year, while most other strains have a considerable proportion of such spawners (Edwards 1978).

Semi-natural selection as an adaptation to life in captivity is also difficult to measure. Gjerde (1983) found when evaluating his selected fish that the unselected control showed higher growth rates than the control population consisting of offspring from wild-caught salmon. This difference was explained by supposing that the unselected farmed fish grew better than first generation culture fish because they had undergone selection for life in captivity during three to four generations. Domestication is also claimed to affect salmon behavior as the farmed salmon behave today more as a "tame" animal than in the early 1970's.

SPECIFIC PROBLEMS IN BROODSTOCK MAINTENANCE

During the first year of salmon culture, eggs were collected from wild-caught salmon. This situation could not persist long for at least two reasons. Firstly, the amount of eggs needed for the growing fish farming industry soon became much larger than the relatively sparse natural salmon populations in Norway could support. Secondly, a selective breeding program presupposes the control of the breeding phase.

Practical experience with eggs of farmed salmon gave variable and rather poor results the first years (Ulgenes and Nævdal 1984, 1985). These problems were mainly related to egg survival, as well as to the poor survival of the broodstock the last weeks or months before ovulation. Also, abnormal maturation frequently was recorded. The breeding season became very long because of great individual variation in ovulation time, and frequently the ovulation process was prevented although the maturation of the eggs evidently was normal. The problems encountered with broodstock maintenance have been described by a group of research workers, extension workers and fish farmers (Anon. 1985). This group concluded that the problems evidently had several causes, i.e. physical environmental factors such as salinity and temperature during the maturation process, handling of broodstocks and eggs and nutrition of broodstock, especially diets with inadequate content of certain vitamin and possibly mineral food components. The situation now is reasonably good. The greater part of the broodstock is transferred to fresh or brackish water 2-3 mo before ovulation. Fish selected for broodstock are fed a specially prepared broodstock feed during their last months of feeding. This feed contains an extra supply of vitamins and microminerals, as well as increased amounts of protein and decreased fat content compared to ordinary dry feed. However, still unexplained mortalities of eggs and alevins occur which seem to be related to the egg quality.

Experiments are now under way for regulation of ovulation time by hormones or manipulation of environmental factors. Light regulation has shown to be especially effective for regulation of spawning time without affecting the egg quality (Taranger et al. 1987).

Egg production of rainbow trout has met with the same problems as Atlantic salmon, but to a lower degree. Based upon physiological changes and survival experiment, Albrektsen and Torrissen (1988) found the temperature was more important than salinity for normal maturation and survival of rainbow trout broodstock eggs, although there seemed to be a complex interaction between the effects of these factors. Best survival was obtained in brackish water (15%) regardless of temperature.

BROODSTOCK FOR ENHANCEMENT AND SEA RANCHING

Atlantic salmon have been released in Norwegian rivers for many years to enhance local stocks. They have mostly been released as unfed fry (10-15 million a year), but also as underyearlings or smolt. Smolts (400,000-500,000 a year) are released primarily to compensate for damage to recruitment caused by river regulations (Hansen et al. 1987). Ocean ranching has so far been carried out on an experimental basis only, although the results have been most encouraging (Hansen and Jonsson 1989), and such activity may be started on a larger scale in the near future.

For many years, the released fry were offspring from salmon of unknown origin, also farmed fish. In principle, only endemic fish are allowed to be used for enhancement of natural stocks to protect the between-strain variation. Only when such fish are unavailable should non-indigenous fish be allowed to be used. At present, most fish released are from local stocks (Ståhl and Hindar 1988).

INTERACTIONS BETWEEN CULTURE AND NATURAL SALMON POPULATIONS

Ståhl and Hindar (1988) made a comprehensive monograph of the Norwegian salmon stocks with reference to the population structure, number of spawners (population size) and differences within and between wild and farmed salmon stocks. From studies on biochemical genetics, they concluded that natural salmon are divided into genetically distinct populations, sometimes more than one within the same river system. Farmed salmon (commercial stocks for intensive farming and culture stocks) is not a homogeneous group. It is not possible to distinguish between wild and cultured salmon on the individual level by use of biochemical gene markers.

Skjervold (1988) gave an overview of the types of genetic impacts fish farming could have on natural salmon stocks. In spite of the difficulties in estimating the numbers of escapees from fish farms, and the magnitude of their contribution to the recruitment of salmon, evidently a great potential exists of significant gene transfer risk from farmed salmon to wild stock.

The origin of the salmon used for fish farming is important. As far as we know, there have been no imports of live salmon from the western Atlantic to Norway (except for scientific purposes). For several years, however, we have imported smolt from Iceland, Scotland and especially from Sweden and Finland (Baltic salmon). Gjedrem and Aulstad (1974) observed that a strain of Baltic salmon showed much lower resistance to vibrio than the Norwegian strains, indicating that genetic differences in resistance to certain diseases exist between geographically distant groups. Escape of fish with adaptations to diseases and parasites in their home environment will represent a risk of transferring such disease agents to populations in a new environment. The indigenous populations may even be eradicated as a result of spontaneous or accidental disease outbreaks in the non-indigenous fish.

Low numbers of spawners (effective population size) will always increase genetic drift, decrease heterozygosity and, consequently, increase the risk of loss of genes. A number of 100 specimens of each sex is recommended by Allendorf and Ryman (1987), but in several cases of artificial reproduction for enhancement work and intensive fish farming, the spawning populations are considerably less than recommended based on theoretical considerations. However, the results of Ståhl and Hindar (1988) show that the heterozygosity is higher in artificial than in most natural populations, and the genetic variability within populations is not reduced due to culture activities. This may be because cultured populations usually represent different natural populations and contain more genetic variation than any single population. Therefore, the risk of reducing the fitness of salmon through reduced genetic variability does not seem to be serious for the moment, although it should be kept in mind by monitoring both cultured and natural populations through several generations.

In conclusion, the escapement of farmed salmon and the liberation of non-indigenous salmon for enhancement work represent a risk of decreasing the genetic variability between populations, possibly also reducing the long-time fitness in spite of possible hybrid vigor in adaptive traits through hybridization between indigenous and non-indigenous fish. However, discussions on this topic are often loose and concentrate more on potential impacts than on actual facts. The scientific challenge for the future will be to base this discussion on observed or experimental data. Further studies on genetic differentiation of natural populations is also important. The use of gene markers is a promising method to study hybridization and gene introgression. For other species (cod, brown trout), broodstocks homozygotous for specific gene markers (biochemical or morphological) are developed (Skaala et al. 1990). No suitable markers are yet found for salmon, but this will be further investigated for application in field studies on interaction between populations. If such studies are difficult or impossible to perform with salmon, they will be performed with brown trout as a model species.

Improvement of technical methods to prevent escapement is an immediate initiative to prevent contact between wild and cultured salmon. Usually, the security of a fish farming facilty is a compromise between the chance of loss and the cost of investment. Land-based facilities are more safe than ordinary net pens, and closed or semiclosed pens are also an alternative. For the moment, land-based facilities for marine culture are not common in Norway, but closed or semiclosed systems are under development. At present, there is no specific demand for such fish farming devices, but in the proposed protective areas for salmon, new farming activities will not be allowed unless they are secured with respect to escapement, thus preventing contact between natural and farmed salmon (see below).

Salmon from *Gyrodactylus*-treated streams are maintained by means of artificial breeding and release and this would apply in intensive culture as well (Ståhl and Hindar 1988). A sampling program for deep-freezing of sperm has been undertaken (Gausen 1986, Egidius et al. 1988). In 1986, sperm from 48 strains was preserved, while in 1987, the sperm bank increased to contain sperms from 69 populations. By using such sperm, populations which have been eradicated may at least be partially reconstructed. The use of androgenetic techniques would allow the more complete reconstruction of natural populations from sperm banks (Scheerer et al. 1986).

For many years, there has been a lack of smolts for the fish farming industry in Norway as smolt production did not increase as fast as the development of food fish production. For this reason, some imports were legislated and, in some cases, with disastrous results with both cultured salmon (i.e. import of furunculosis from Scotland) and natural populations (possible import of *Gyrodactylus salaris* from Baltic countries). In 1988 there was a surplus of smolts in Norway. This situation is expected to persist, and there is no longer any reason for the import of live salmon. However, in 1988 there was an importation of salmon eggs from Iceland. Transport of live material within the country has probably also contributed to the spread of *Gyrodactylus*. This seems to be a problem, especially in cases where salmon farms are situated in freshwater systems also supporting anadromous salmonids, or in brackish water with a salinity lower than 14-18 o/oo. For this reason, restrictions of transfer within Norway are also practiced.

Hatcheries for commercial production of smolts for intensive fish farming are usually not located in or close to rivers with anadromous salmonid populations. However, some existing hatcheries are located close to rivers with sea-run fish, and inland in Norway rearing facilities for rainbow trout production (mostly small) are sometimes located in lakes draining into salmon rivers. Such fish farms have probably spread *Gyrodactylus salaris*. New installations for intensive production or for enhancement work for other than indigenous populations will no longer be allowed in rivers supporting anadromous populations.

To protect larger areas, a plan has been introduced for time restricted protective areas for wild salmonids. The aim of the plan is to protect larger areas and secure references for observation of gene introgression and spread of disease agents. To prevent the further spread of *Gyrodactylus salaris*, no new culture activities will be allowed where this parasite has been found. This includes the river drainage and a defined area usually within about 20 km of the river mouth. Usually, rivers having a mean annual catch of more than 500 kg anadromous salmonids are protected. A few of the larger fjord areas (Sognefjorden, Trondheimsfjorden) are also to be held free from new aquaculture installations. Such protective areas are proposed for 5 years as it is desirable to gain experience about the effect of such restrictions before long-lasting decisions are made. If escapement-free facilities are constructed, limited farming activities may be allowed, and existing farms within the areas will be allowed to continue.

INTERSPECIFIC HYBRIDIZATION, SINGLE LOCUS VARIATION IN PRODUCTIVE TRAITS, CHROMOSOME ENGINEERING AND GENE TECHNOLOGY

Hybridization between salmonid species was regarded in the 1970's as a potential tool for producing sterile fish with enhanced growth rates due to hybrid vigor. Limited studies were carried out (Foldøy 1975; Refstie and Gjedrem 1975; Refstie 1983). However, although congeneric hybrids were viable and showed reasonable high growth rate, the studies were terminated because, as an overall consideration, the pure species were more valuable. This conclusion is further supported by the fact that hybrids appear different from the parent species, and they are not known and accepted by the market.

Single locus variations with a clear effect on growth rate were found by Torrissen (1987) in a trypsin-like isozyme of Atlantic salmon. Transferrin variation may have similar effects on disease resistance (Kjell Arne Rørvik, AKVAFORSK, pers. comm.), and possibly also genetic variation in the immune responses which have been found in preliminary studies at the University of Bergen.

Chromosome engineering has been studied for several years at the Institute of Aquaculture Research, Division Sunndalsøra, where biological and technical studies on gynogenesis and triploidy have been carried out (Refstie et al. 1977; Holmefjord et al. 1982). The results are promising, especially those producing all-female, triploid sterile individuals by combining triploidization with gynogenesis or sex reversal. These techniques have not yet been applied on a commercial scale.

Several laboratories have undertaken studies on gene technology. Isolation of gene coding for growth hormones, prolactine, insuline or "disease resistance" has been initiated with the double aim of conducting basis studies on such mechanisms and of transferring "valuable" genes within and between species. Both Atlantic salmon and a model fish species (zebra fish) are used for such investigations. Another aspect of these investigators is the construction of "genome libraries" and studies on the homeobox-genes of salmon. The laboratories engaged in gene technology studies on fish in Norway are listed in Appendix I.

REFERENCES

Albrektsen, S., and O. J. Torrissen. 1988. Physiological changes in blood and seminal plasma during the spawning period of maturing rainbow trout held under different temperature and salinity regimes, and the effect on survival of the broodstock and the eyed eggs. Coun. Meet. Int. Counc. Explor. Sea 1988(F:3): 1-24 (mimeo).

Allendorf, F. W., and N. Ryman. 1987. Genetic management of hatchery stocks. In Ryman, N., and F. Utter (ed.) Population genetics and fisheries management. Wash. Sea Grant Program, University of Washington Press, Seattle.

Anon. 1985. Oppdrett av stamfisk og klekking av lakserogn. Sluttrapport fra Stamfiskutvalget. Fisken og Havet, Ser. B. 1985 (I): 1-127 (in Norwegian).

Anon. 1987. Institute of Aquaculture Research. The Agricultural Research Council of Norway, 37 p.

Anon. 1988. There are fish, and there are fish.... Leaflet published by the Norwegian Fish Farmers' Breeding Centre AS. P. O. Box 230, N-7201 Kyrksæterøra.

Berg, M. 1964. Nord-norske lakseelver. Johan Grundt Tanum Forlag, Oslo 1964, 300 p. (in Norwegian, English summary).

Edwards, D. J. 1978. Salmon and trout farming in Norway. Fishing News Books Ltd., Farnham, Surrey, England, 1988.

Egidius, E., L. P. Hansen, B. Jonsson, and G. Nævdal. 1988. Mutual impact of wild and cultured Atlantic salmon in Norway. Coun. Meet. Int. Counc. Explor. Sea 1988 (Mini 5): 1-16.

Foldøy, J. 1975. Artshybrider mellom laksefisk. Befruktning, fosterutvikling, dødelighet og overlevelse på yngelstadiet. Master's Thesis, The University of Bergen (in Norwegian).

Gausen, D. 1986. Bavaring av naturlige genressurser hos laksefisk. Direktoratet for naturforvaltning, Fiskekontoret, Trondheim, Norway.

Gjedrem, T. 1976. Possibilities for genetic improvement in salmonids. J. Fish. Res. Board Can. 33: 1094-1099.

Gjedrem, T. 1983. Genetic variation in quantitative traits and selective breeding fish and shellfish. Aquaculture 33: 51-72.

Gjedrem, T., and D. Aulstad. 1974. Selection experiments with salmon. I. Differences in resistance to vibrio disease of salmon parr *Salmo salar*. Aquaculture 3: 51-59.

Gjedrem, T., and B. Gjerde. 1986. Arveleg variasjon i overleving ved Hitrasjuke, p. 5. In Hjeltnes, B. (ed.) Frisk fisk. Information leaflet from a program committee on fish health (in Norwegian).

Gjedrem, T., and K. Gunnes. 1978. Comparison of growth rate in Atlantic salmon, pink salmon, char, sea trout and rainbow trout under Norwegian farming conditions. Aquaculture 13: 135-141.

Gjerde, B. 1983. Avlsarbeid med laks og regnbogeaure. Gjennomføring og resultat. Contribution to conference on selection and smolt quality in Norwegian fish farming. Fiskeoppdrett '83, 19 p. (in Norwegian).

Gjerde, B. 1984. Response to individual selection for age at sexual maturity in Atlantic salmon. Aquaculture 38: 229-240.

Gjerde, B. 1986. Growth and reproduction in fish and shellfish. Aquaculture 57: 37-55.

Gjerde, B. 1987. Predicting carcass composition of rainbow trout by computerized tomography. J. Anim. Genet. 104: 121-136.

Gjerde, B. 1989. Body traits in rainbow trout. I. Phenotypic means and standard derivations and sex effects. Aquaculture 80: 7-24.

Gjerde, B., and T. Gjedrem. 1984. Estimates of phenotypic and genetic parameters for carcass traits in Atlantic salmon and rainbow trout. Aquaculture 36: 97-110.

Gjerde, B., and H. Martens. 1987. Predicting carcass composition of rainbow trout by near infrared reflectance spectroscopy. J. Anim. Genet. 104: 137-148.

Gjerde, B., and L. R. Schaeffer. 1989. Body traits in rainbow trout. II. Estimates of heritabilities and of phenotypic and genetic correlations. Aquaculture 80: 25-44.

Gunnes, K. 1987. Case study of a large-scale breeding programme. Norwegian salmonid programme for production of food fish, p. 379-382. In Tiews, K. (ed.) Proc. World Symp. on Selection, Hybridization and Genetic Engineering in Aquaculture. Bordeaux, 27-30 May 1986, Vol. II, Berlin.

Hansen, L. P., and B. Jonsson. 1989. Salmon ranching experiments in the River Imsa: effect of timing on Atlantic salmon (Salmo salar) smolt migration on survival and adults. Aquaculture 82: 367-373.

Hansen, L. P., R. A. Lund, and K. Hindar. 1987. Possible interaction between wild and reared Atlantic salmon in Norway. Counc. Meet. Int. Counc. Explor. Sea 1987 (M:14): 18 p.

Hansen, T., K. Jørstad, R. Lerøy, O. Torrissen, and G. Nævdal. 1988. Productive traits of salmon families along the Norwegian coast. Contribution to 3rd Int. Symp. on Genetics in Aquaculture, Trondheim, Norway, June 198, 11 p.

Holmefjord, I., T. Refstie, and J. Høstmark. 1982. Preliminary results on induction of triploidy in salmonids using heat shocks. Europ. Assoc. Anim. Product., Comm. Anim. Genet., Leningrad, 8 p.

Nævdal, G. 1983. Genetic factors in connection with age at maturation. Aquaculture 33: 97-106.

Nævdal, G., M. Holm, R. Lerøy, and D. Møller. 1978. Individual growth rate and age at first sexual maturity in Atlantic salmon. Fiskeridir. Skr. Ser. Havunders. 16: 519-529.

Nævdal, G., R. Lerøy, and D. Møller. 1983. Sources of variation in weights and length of Atlantic salmon. Fiskeridir. Skr. Ser. Havunders. 17: 359-366.

Refstie, T. 1983. Hybrids between salmonid species. Growth and survival in seawater. Aquaculture 33: 181-185.

Refstie, T., and T. Gjedrem. 1975. Hybrids between Salmonidae species. Hatchability and growth rate in the freshwater period. Aquaculture 6: 333-342.

Refstie, T., and T. A. Steine. 1978. Selection experiments with salmon. III. Genetic and environmental sources of variation in length and weights of Atlantic salmon in the freshwater phase. Aquaculture 14: 221-234.

Refstie, T., V. Vassvik, and T. Gjedrem. 1977. Induction of polyploidy in salmonids by Cytochalasin . Aquaculture 10: 65-74.

Scheerer, P. D., G. H. Thorgaard, F. W. Allendorf, and K. L. Knudsen. 1986. Androgenic rainbow trout produced from inbred and outbred sperm sources show similar survival. Aquaculture 57: 289-298.

Skilbrei, O. 1985. Vekstmønster hos laks (*Salmo salar*) i ferskvannsog sjøfasen. Master's Thesis. The University of Bergen, 131 p. (in Norwegian).

Skjervold, H. 1988. Kan enkelte kulturtiltak true våre laksestammer? p. 14-21. In Lindgren, B. (ed.) Fagmøte om sikringssoner for laksefish. Stjørdal, Norway.

Ståhl, G., and K. Hindar. 1988. Genetisk struktur hos norsk laks: status og perspektiver. Rapp. fra Fiskeforskningen, Direktoratet for naturforvaltning (I): 1-57 (in Norwegian).

Skaala, Ø, G. Dahle, K. E. Jørstad, and G. Nævdal. 1990. Interactions between natural and farmed fish populations: information from genetic markers. 3rd Int. Symp. on Genetics in Aquaculture. Abstract, p. 47. Trondheim, Norway, June 1988.

Taranger, G. L., S. Stefansson, and T. Hansen. 1987. Off season ovulation of farmed Atlantic salmon. Contrib. Symp. on Fish Reproduction, Poster Session. Newfoundland, August 1987.

Tofteberg, P., and T. Hansen. 1987. Relationship between age at maturity and growth rate in farmed rainbow trout, *Salmo gairdneri*. Proc. World Symp. on Selection, Hybridization and Genetic Engineering in Aquaculture, Bordeaux, May 1986, Berlin 1987.

Torrissen, K. 1987. Genetic variation of trypsin-like isozymes correlated to fish size of Atlantic salmon (*Salmo salar*). Aquaculture 62: 1-10.

Torrissen, O. J., and G. Nævdal. 1984. Pigmentation of salmonids - genetical variation in carotenoid deposition in rainbow trout. Aquaculture 38: 59-66.

Torrissen, O. J., and G. Nævdal. 1988. Pigmentation of salmonids - variation in flesh carotenoids of Atlantic salmon. Aquaculture 6: 306-310.

Ulgenes, Y., and G. Nævdal. 1984. Problems with broodstock husbandry and low hatching output in Norwegian commercial hatcheries. Int. Symp. on Salmonid Reprod., Bellevue, Washington, USA, Oct. 31-Nov. 2, 1983 (poster session).

Ulgenes, Y., and G. Nævdal. 1985. Causes variation in viability of reared Atlantic salmon (*Salmo salar*) broodstock and eggs. Symp. Aquaculture in Subarctic Areas, Umeå, Sweden, June 1985.

Appendix I. Laboratories Engaged in Gene Technology Studies on Fish in Norway

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Årstad, N-5029 Bergen

Marine Genetics
c/o Laboratory for Biotechnology (address above)

Zoological Laboratory, The University of Bergen
Allegt. 41, N-5007 Bergen

Department of Biochemistry, The University of Bergen
Åstadveien 19, N-5009 Bergen

Department of Biochemistry, Norwegian Technical University
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Department of Genetics and Biotechnical Disease Control
Norwegian Veterinarian University, P. O. Box 8146 Dep. N-0033 Oslo 1

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Norwegian Fisheries High School, The University of Tromsø
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SALMONID NUTRITION AND FEED PRODUCTION

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ABSTRACT

Lall, S. P. 1991. Salmonid nutrition and feed production p. 107-123. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

The current status of the nutrient requirement of salmonid fishes and fish feed technology is briefly reviewed. Although understanding of the feeding and nutrition of salmon and trout has been expanding steadily in the past 15 yr, the quantitative nutrient requirements of rainbow trout (*Salmo gairdneri*) is better defined than other species. The rapid growth of Atlantic salmon (*Salmo salar*) farming has resulted in the development of high energy diets to maximize production. Studies on broodstock nutrition have revealed the role of vitamins, trace elements and essential fatty acids in reproduction and successful hatchability of eggs in certain fishes. In recent developments in the areas of nutrition and immunity, salmonids as a source of omega-3 fatty acids for humans and diet and pollution are also discussed.

Several types of feeds are now utilized in fish production, including wet, semi-moist, dry steam pellets and dry extruded (expanded) pellets. The advantages of these feed processing techniques and their effects on nutrient stability are considered.

RÉSUMÉ

Lall, S. P. 1991. Salmonid nutrition and feed production p. 107-123. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

On fait brièvement ici le point sur les besoins en nutriments des salmonidés et sur la technologie des aliments du poisson. Bien que les connaissances sur l'alimentation et la nutrition du saumon et de la truite n'aient cessé de s'accroître depuis 15 ans, on connaît mieux les besoins en nutriments de la truite arc-en-ciel (*Salmo gairdneri*) que ceux des autres espèces de salmonidés. La croissance rapide de la pisciculture du saumon de l'Atlantique (*Salmo salar*) a nécessité l'élaboration de régimes alimentaires très énergétiques pour maximiser la production. Les études de la nutrition des géniteurs ont mis en évidence le rôle des vitamines, des éléments traces et des acides gras essentiels dans la reproduction et l'éclosabilité des oeufs de certains poissons. Au chapitre des progrès récents dans la nutrition et l'immunité, on traite de l'utilisation des salmonidés comme source d'acides gras oméga 3 pour les humains, ainsi que de l'alimentation et de la pollution.

Les pisciculteurs utilisent maintenant plusieurs types d'aliments, dont les granulés humides et semi-humides, les granulés séchés à la vapeur et les granulés secs extrudés (expansés). On étudie les avantages respectifs des diverses techniques de préparation de ces aliments et leurs effets sur la stabilité des nutriments.

INTRODUCTION

The science of fish nutrition has advanced rapidly over the past 15 yr, especially in the field of salmonid nutrition. Of several species of trout, salmon and charr cultured for stocking of lakes and rivers, ocean ranching and marine net-pen culture, nutrient requirements of rainbow trout (*Salmo gairdneri*) are most extensively studied. In recent years, research on nutrition of Pacific salmon (*Oncorhynchus tshawytscha, O. kisutch* and *O. gorbuscha*), Atlantic salmon (*Salmo salar*) and Arctic charr (*Salvelinus alpinus*) has been undertaken by several research institutions in Europe, United States, Canada and Japan. Unfortunately, most of the information on the nutrient requirements of these fish is confined to young, rapidly growing fish.

Interest in fish nutrition dates back to 1918 when Embody fed vegetable and animal meals to trout unsuccessfully. Early researchers relied on natural foods, fresh animal meat and fishery by-products for feeding fish. Biologists approached the problems of fish nutrition by investigating the effect of natural foods on fish. In 1924, Embody and Gordon studied the chemical composition of the natural food of wild trout. He found that the proximate composition of various insects consumed by the trout had 49% protein, 15-16% lipid, 8% fiber and 10% ash. It is not surprising to note that these values resemble the composition of existing trout diets. Later, nutritionists attempted to substitute, on a nutrient basis, other materials in feed formulations. It is on this foundation that our knowledge of nutritional requirements of fishes has evolved.

A brief history of diet development has been recently reported by Hardy (1989) and is beyond the scope of this paper. Early fish feeds based on chopped fish and slaughterhouse products caused disease problems. The development of Oregon moist pellets in the 1950's was a major breakthrough for the eradication of disease and development of Pacific salmon hatcheries in U.S.A. A successful dry diet was developed for rainbow trout by Phillips et al. (1964). In the early 1970's, many successful hatchery diets were developed for rainbow trout at Spearfish Diet Development Center in South Dakota and University of Guelph in Canada and for salmon at Abernathy Diet Development Center in Washington. Since then, many institutions are actively involved in fish feed developments in several countries.

The problem of vitamin deficiencies was widely recognized by nutritionists in the 1930's. McLaren et al. (1947) were the first to introduce a purified diet for the qualitative and quantitative requirements of vitamins. Despite their original research efforts, unavailability of feed ingredients sufficiently free of vitamins prevented them from the characterization of vitamin deficiencies. In 1957, Halver developed a complete semi-purified diet which led to the quantitative determination of fat and water soluble vitamins and amino acid requirements. In recent years, several investigators have modified this diet to study the nutrient requirements of other finfish.

A comprehensive review of salmonid nutrition and feed production is impossible in this paper; I have attempted to provide an overview of the research and development in this area. Recent publications (NRC 1981; Cowey et al. 1985; Halver 1989) may be referred for more specific details on this subject.

NUTRIENT REQUIREMENTS OF FISH

In order to develop successful feed formulas, basic information is required on the nutrient requirements, the organoleptic properties of feed in relation to acceptability and ability to utilize nutrients from various sources. Although the nutrient requirements of salmonids have been investigated for over 50 yr, only in the past decade have research efforts been directed towards species other than rainbow trout. The nutrient requirements of salmonids should be considered at various stages of development including fry, parr, smolt, postsmolt and broodstock stage. Investigations on feeding and nutrition of fish reared in seawater and broodstock have been slow. The following section summarizes the role of major nutrients, i.e. protein and amino acids, lipid, carbohydrate, energy, vitamins and minerals in salmonid nutrition.

PROTEIN

The protein nutrition is the most complex area of nutrition. The requirements of calories, carbohydrates, vitamins and minerals are meaningless without indications of the level and characteristics of protein in the diet. The utilization of protein decreases as its level in the diet increases. Many factors other than the level of protein also affect the energy level, type of protein, water temperature and salinities, etc. Differences in the amino acid requirements among species and the availability of amino acid in question will also affect protein utilization.

The natural diet of fish is rich in protein. Generally, fish require a higher percentage of protein in their diets than birds and mammals. This may be because fish utilize carbohydrates less efficiently and some protein is metabolized for energy. Experiments in feeding fry, fingerlings and yearling fish have shown that gross protein requirements are highest in the initial feeding of fry and decrease as fish size increases. In order to achieve a maximum growth rate, fry must receive a diet in which nearly half of the digestible ingredients consist of a balanced protein. Their protein requirement decreases to about 40-44% of the diet at the later stages of development.

It has been shown that salmonids cannot synthesize the following amino acids at a sufficient rate to meet the requirements of growth: arginine, lysine, tryptophan, methionine, leucine, isoleucine, histidine, phenylalanine, valine and threonine. The essential amino acid requirements are very similar for coho salmon, sockeye salmon and rainbow trout (Table 1). The amino acid requirement of fish was recently reviewed by Wilson and Halver (1986). In fish, the requirements for many amino acids are more than twice those of omnivorous terrestrial mammals. However, a net nitrogen retention of protein by fish is not greater than that of mammals. This indicates that there are important differences in amino acid catabolism between carnivorous fish and omnivorous land mammals.

In order to obtain maximum growth and protein utilization, the protein should be selected to create an amino acid supply close to the requirement. A sound policy of protein utilization is to rely on a variety of protein sources in the diet because they are likely to be more complete and balanced in amino acids than a single protein source.

LIPID

Dietary lipid supplies both energy and essential fatty acid (EFA) in salmonid diets. They also act as carriers of fat-soluble vitamins and carotenoid pigments. It has been shown that basic differences exist between the lipid of fish and domestic animals. Fish lipid contains a high level of polyunsaturated fatty acids, mainly of the linolenic series (n-3 type), whereas mammalian lipids contain more saturated fats than the unsaturated lipids of the linolenic series (n-6). All salmonids cannot synthesize fatty acids of n-3 and n-6 series. These must be provided in the diet. The EFA requirement of fish differs among various salmonids (Table 2). It is well known that characteristic differences exist in the fatty acid composition and EFA requirement of various freshwater and marine fish species (Watanabe 1988). The EFA requirement of most salmonids in a seawater environment has not been investigated.

Freshwater fish require 18:2 n-6 and/or 18:3 n-3, whereas marine fish require n-3 highly unsaturated fatty acids (HUFA) such as 20:5 n-3 and 20:6 n-3. The HUFA required by marine fish have been shown to be effective in prevention of EFA deficiency signs in freshwater fish. Salmonid diets contain 10-24% crude fat. Diets are usually supplemented with animal, marine and vegetable fats or a mixture of these to supply an adequate level of energy and EFA. Commercial salmonid diets containing fish meal generally supply 4-6% lipid as fish oil where the lipid fraction of fish meal may contain n-3 fatty acids (major proportion 20:5 and 22:6) in a range from 0.4-0.6% or higher. These diets may provide sufficient EFA to meet the dietary requirement of salmon and trout. A high level of HUFA in the diet causes a difficulty in maintaining fat stability during diet storage. Dietary antioxidant and vitamin E supplements are essential to protect them from oxidation in feed and *in vivo* tissue lipid peroxidation, respectively.

CARBOHYDRATES

Salmonids have a limited ability to utilize carbohydrate for energy purposes. Although the basic pathway of carbohydrate metabolism in fish is similar to that of other animals, there appears to be some basic differences in the utilization of carbohydrates. Some workers have reported that a carbohydrate level as high as 25% of the diet

Table 1. Essential amino acid requirements of certain salmonids[a].

Amino acid	Rainbow trout	Chinook salmon	Coho salmon
Arginine	3.3 (1.2/36)[b]	6.0 (2.4/40)	5.8 (2.3/40)
Histidine	-	1.8 (0.7/40)	1.8 (0.7/40)
Isoleucine	-	2.2 (0.9/41)	-
Leucine	-	3.9 (1.6/41)	-
Lysine	3.7 (1.3/35)[c]	5.0 (2.0/40)	-
Methionine	3.0 (1.1/35)[d]	4.0 (1.6/40)	-
Phenylalanine	-	5.1 (2.1/41)	-
Threonine	-	2.2 (0.9/40)	-
Tryptophan	1.4 (0.58/42)[e]	0.5 (0.2/40)	0.5 (0.2/40)
Valine	-	3.2 (1.3/40)	-

[a] Based on Wilson and Halver (1986). Requirements are expressed as percentage of protein. In parenthesis, the numerators are requirements as percentage of diet and denominators are percentage of total protein in diet.

[b] Other values reported, 4.0(1.4/35) and 5.9(2.8/47).

[c] Other values reported, 4.2(1.9/45) and 6.1(2.9/47).

[d] Other values, 2.2(1.0/46.4), 2.9(1.0/35).

[e] Other value, 0.5(0.25/55).

Table 2. Essential fatty acid requirements of certain salmonids.

Species	Requirement		Reference
Rainbow trout	18:3 n-3	1%	Castell et al. (1972)
	18:3 n-3	0.83-1.66%	Watanabe et al. (1974)
Chum salmon	18:2 n-6	0.5%	Takeuchi et al. (1980)
	18:3 n-3	0.5%	
Coho salmon	Tri-18:3 n-3	1-2.5%	Yu and Sinnhuber (1979)
Yamane (*O. masou*)	18:3 n-3	1% or	Watanabe et al. (1986)
	n-3 HUFA	0.5%	

may be used efficiently by fish, while others have found 12% of the diet to be the maximum tolerable level. Some of the differences in carbohydrate utilization in these studies could be attributed to species differences, age and size of fish, water temperature and the form of carbohydrate used. The digestibility of starch derived from cereal grain is poor, but processing methods utilizing heat improve the availability of carbohydrates. Excessive amounts of carbohydrates in the salmonid diet are deleterious, producing abnormally high glycogen levels in the liver, slow growth and mortalities, particularly at low temperatures.

ENERGY

Dietary lipid, carbohydrate and protein serve as sources of energy. It is generally accepted that fish rely to a large extent on lipid and protein rather than on carbohydrate for energy. Whether protein calories are used for catabolic or anabolic purposes is dependent on the availability of fat and carbohydrate calories to spare the protein for tissue production and on the quality of protein for the fish. Evidence indicates that high protein intake is nutritionally wasteful in terms of the amount of energy required for the oxidation of protein. Despite their high protein intake, the protein deposition per unit of energy intake is significantly greater in salmonid fish than birds or mammals (Smith 1989).

The gross energy of ingested feed is divided into several metabolic pathways. Gross energy, digestible energy (DE) and metabolizable energy (ME) have been used frequently to measure the food energy of fish. A controversy exists whether DE or ME data should be used for the evaluation of fish feeds. Theoretically, ME should be superior to DE because it accounts for energy losses from protein via the urine and the gills. However, it is difficult to measure quantitatively the urinary and branchial ammonia excretions to determine the metabolizable energy measurements of fish. For practical feed formulations, the DE data of conventional feed ingredients is considered adequate. When new products are available for use in fish feeds, their ME values must be evaluated. The subject of the energy requirement of finfish has been discussed in detail by Cho and Kaushik (1985).

MINERALS

Unlike terrestrial animals, salmonids have the ability to absorb some inorganic elements, not only from their diets, but also from their external environment, both in fresh water and seawater. At least part of their requirement for calcium cobalt, iron, magnesium, potassium, sodium, zinc and others can be obtained directly from the water. Certain minerals such as chlorides, phosphates and sulfates are more effectively obtained from feed sources.

At present, 26 of the 90 naturally occurring elements are known to be essential for animal life. Although most of the minerals required by the terrestrial animals have been detected in the tissue of salmonid fishes, only the requirement of nine minerals (Table 3) have been reported in selected species (Lall 1989). In recent years, nutritional deficiencies of phosphorus, magnesium, iron, zinc, copper, manganese and selenium have been characterized. Undoubtedly, many gaps exist in the knowledge of the basic requirements of inorganic elements for optimum physiological functions in most fishes. In the past, fish meal was considered an adequate source of minerals in commercial feeds. It is now becoming apparent that some fish meal containing high levels of ash may affect trace element availability from the diet.

VITAMINS

The quantitative vitamin requirements of several species of salmonids for most vitamins have been evaluated and deficiency symptoms described. An excellent detailed review of this subject has been published (Halver 1989) and is beyond the scope of this paper.

A continuing problem regarding the instability of vitamin C has existed in fish feeds. Ascorbic acid (ASA) stability is influenced by the moisture content of the diet, processing methods, storage conditions and the presence of rancid oil and fats. In recent years, several stable forms of vitamin C have been introduced. They include fat or ethyl cellulose coated vitamin C and various esterified forms of this compound (L-ascorbic acid palmitate, ascorbate-2-sulfate and L-ascorbyl-2-polyphosphate). Most of these compounds are relatively stable in feed; however, additional information is required on their

Table 3. Mineral requirements of certain salmonids (in percentage or amount per kg feed)[a].

Species	Calcium (%)	Phosphorus[b] (%)	Magnesium (%)	Iron (mg)	Copper (mg)	Manganese (mg)	Zinc (mg)	Iodine (µg)	Selenium (mg)
Rainbow trout	0.02	0.7	0.05	-	3	13	15-30	R	0.15-0.38
Atlantic salmon	0.03	0.6	R	60	5	20	R	R	R
Chinook salmon	-	R	-	-	-	R	R	0.6-1.1	R
Chum salmon	-	0.6	-	-	-	R	R	R	R

[a] R, required.
[b] Inorganic phosphorus.

bioavailability to fish to determine their potential in tissue saturation, disease prevention and successful reproduction.

ALTERNATE SOURCES OF PROTEIN AND LIPID

PROTEIN SOURCE

Fish meal constitutes the major portion of protein in commercial diets. Fish meal made from whole herring, capelin, menhaden and anchovy are generally utilized in feed formulation. High quality fish meal is a complete source of amino acids on the basis of analytical data. It contains high levels of available lysine and methionine which are deficient in plant protein supplements. Fish meal also contains essential trace elements and a bioavailable form of phosphorus. However, fish meal made from fish filleting waste and white fish contains excessive levels of ash. These fish meals cause trace element bioavailability problems. The lipid present in the fish meal also supplies 1-3% n-3 fatty acids.

The growth of the aquaculture industry has created a higher demand for fish meal and the shortage of this product is becoming imminent. Despite the high nutritional value of fish meal, research for alternate sources of protein is continuing in several laboratories. Although soybean meal could partially replace fish meal in salmonid diets, a level exceeding 15-18% causes low palatability of Atlantic salmon diets, particularly at low temperatures. Soybean meal could successfully replace fish meal; however, a palatability problem develops when the fish meal portion is reduced to approximately 18% of the diet.

The nutritional value of several other potential protein sources for fish feed is also being investigated. These include oilseed meals (canola, cottonseed, safflower, groundnut and rapeseed, etc.), legumes (e.g. lupin, alfalfa), animal by-product meals (meat and bone meals, poultry by-product meal, hydrolyzed feather meal) and brewery by-products, etc. It is well known that the nutritive value of animal and plant protein sources depends on the availablity of essential amino acids. Recently, Higgs et al. (1988) and Asgard (1988) have reviewed the nutritional characteristics of plant and animal feed supplements for aquaculture. Major strategies to improve the nutritive value of plant protein include elimination of antinutritional factors, either through genetic selection, processing or incorporation of feed additives. Several exogenous dietary feed stimulants or attractants are now being tested to improve the palatability of these protein supplements. Certain amino acid deficiency problems may be overcome by the careful selection of feed ingredients and optimization of essential amino acid balance in salmonid diets.

LIPID SOURCE

Dietary lipid supplements serve as a source of energy and essential fatty acids. Generally, vegetable oils are a good source of 18:2 n-3, whereas marine fish oils supply high levels of n-3 fatty acids. These fish oils also contain a significant proportion of 20:5 n-3 and 20:6 n-3 (HUFA). It has been shown that diets containing n-3 HUFA promote growth and their beneficial response far exceeds 18:3 n-3 alone for reproduction in salmonids. In spite of the fact that the part of the energy requirement of fish could be met by vegetable and animal lipid supplements, the EFA requirement is only met by marine fish oil supplements or fish meal.

In order to supply the energy requirement of fish, these lipid supplements must be highly digestible. Animal fats such as lard, tallow or hydrogenated tallow have been used in rainbow trout diets without any adverse effects (Watanabe 1988). However, the hydrogenated oils and animal fats with a high melting point have been reported to be less easily digested than fats of a lower melting point. In recent years, because of the increased demand for n-3 fatty acids in human food and the higher costs of fish oils, feed manufacturers are beginning to incorporate a higher proportion of animal and vegetable supplements in fish feeds.

FISH SILAGE

In certain countries where salmonids are cultured, a considerable volume of marine fish, fishery by-products and underutilized fish species are discarded. These marine products are also being converted into fish silage. The fish silage is commonly defined as the liquified product obtained from whole fish or fish processing wastes which are ground and mixed with acid or fermentable carbohydrates. Enzymes present in the fish break down protein and liquify the fish, while acid prevents microbial spoilage.

Fish silage based diets have been widely used in Scandinavia for both fish and animals. Recently, Lall (1987) has reviewed the pertinent literature on fish silage as feed for salmon and trout. Generally, two methods are used for silage production, ensiling through chemical acidification (acid preserved silage) or bacterial fermentation (fermented silage). A different product, "fish protein hydrolysates," where controlled hydrolysis of fishery wastes by the addition of selected exogenous enzymes occurs, has also been developed. In acid-preserved silage, inorganic and/or organic acids are commonly employed in silage production. Inorganic acids are relatively strong and economical; the final pH of silage must be approximately 2 to prevent bacterial spoilage. On the other hand, organic acid possesses much better antibacterial properties and stable silages have been obtained with formic and propionic acids. Often, a mixture of inorganic acids is used to sufficiently lower pH at low cost and prevent microbial spoilage. For production of fermented silage, bacterial fermentation is initiated by the addition of lactic acid bacteria and fermentable carbohydrates to minced fish. The lactic acid bacteria are naturally present in fish and often starting culture is not necessary.

Studies on the nutritional value of fermented silage is limited. Several workers have successfully utilized acid-preserved silage from spratt, coalfish, capelin, Pacific whiting, dogfish, herring, cod, dogfish offal, trash fish and shrimp waste in salmonid diets (c.f. Lall 1987). Although a characteristic softening gut has been noted in Norwegian farms, no adverse effect on the general performance and flesh quality has been reported. The digestibility of herring, cod and dogfish silage is relatively high (Lall 1989, unpublished results). The performance of Atlantic salmon on a silage-based wet diet and a steam-pelleted diet from a feeding trial conducted under an experimental farm environment in New Brunswick, Canada, is summarized in Fig. 1 (Henderson and Lall 1989). Results clearly indicate that fish silage could successfully replace the herring portion (44%) of the moist feed without any significant adverse effect on growth.

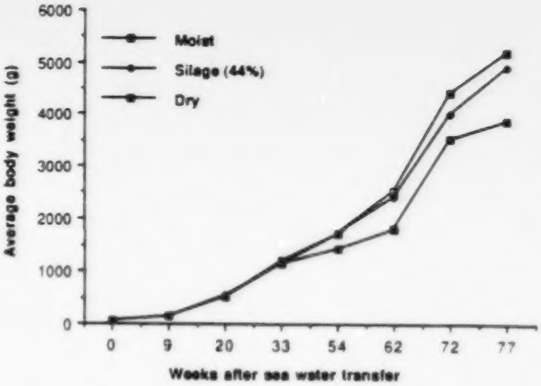

Fig. 1. Growth of Atlantic salmon on moist, silage and dry diets.

CAROTENOID PIGMENTATION

It is well known that the attractive pink to red color of salmonid flesh is due to absorption and deposition of oxygenated carotenoids from the diets. Carotenoid pigments are polyenoic compounds that are widely distributed in both the plant and animal kingdoms. Although plants synthesize carotenoid pigments, crustaceans and animals consuming these pigments deposit them in their shell, flesh and integument.

Salmonid fish absorb a variety of carotenoids from their diet; however, astaxanthin gives the pink to red color to their flesh. In nature, wild salmonids derive astaxanthin from the ingestion of zooplankton, euphausids and other crustaceans and small fish consuming large quantities of these organisms. Generally, fish diets are supplemented with natural feed ingredients, i.e. shrimp, krill, crayfish, red crab, various other crustacean products, algae, paprika and asynthetic canthaxanthin and/or astaxanthin pigments. Since the level of astaxanthin in these natural feed supplements is variable, a relatively high proportion (10-20%) of crustacean by-products is required in the diet to achieve satisfactory pigmentation. These ingredients contain low levels of protein and high level of moisture, ash and chitin, which limits their incorporation at higher levels. Furthermore, astaxanthin esters present in relatively large proportion in shrimp and crab products (oil and meal) are less efficiently absorbed than free astaxanthin (Torrissen and Braekken 1979).

Species differences exist in the digestibility of free astaxanthin (Torrissen et al. 1988).

The metabolism and deposition of astaxanthin and canthaxanthin are not clearly established. In muscle, astaxanthin occurs predominantly in the free form, whereas skin and gonads contain a major proportion of astaxanthin esters. Reports on the retention of astaxanthin are conflicting and show wide variations. Lotil et al. (1979) reported 20-60% retention, where Storebakken et al. (1987) found only 1.7-5% retention. Recently, Torrissen et al. (1988) estimated that astaxanthin and canthaxanthin retention from commercially produced salmon feed (40-75 mg/kg) may range from 4-5% of these compounds.

The distribution of carotenoid levels reported in wild salmonids is summarized in Table 4. Some of these differences are probably attributed to dietary pigment source, stage of development, genetic factors and the method of detection. The relationship between the visual score of flesh pigmentation shows a linear response at low carotenoid levels (Torrissen et al. 1988). These workers recommend a level of 3-4 mg/kg of astaxanthin or canthaxanthin as an acceptable concentration for market size farmed salmon. However, a higher level may be necessary to overcome storage and processing losses.

Table 4. Carotenoid contents of wild salmonid flesh.

Species	Carotenoid level
Atlantic salmon[b,c,d]	3-11
Chinook salmon[a]	8-9
Chum salmon[a,d]	3-8
Coho salmon[a,d]	9-21
Pink salmon[a]	4-6
Rainbow trout[e]	1-3
Sockeye salmon[a,d]	26-37

[a] Kanemitsu and Aoe (1958).
[b] Satio (1969).
[c] Skrede and Storebakken (1986).
[d] Schiedt et al. (1981).
[e] Schiedt et al. (1986).

During sexual maturation, fish mobilize carotenoids from the flesh in the skin and ovaries. In Atlantic salmon, a decrease in the carotenoid content of flesh may occur approximately 6 mo prior to spawning (Torrissen and Torrissen 1985). The increase in the level of carotenoid in the skin of males is significantly higher than females. Several physiological functions of carotenoids in salmonid reproduction have been suggested (Tacon 1981). They include biological roles (hormones, growth promoters, respiratory functions, increased tolerance of eggs to adverse environmental conditions (e.g. elevated water temperature, harmful lighting conditions)) and enhanced chemotaxis of spermatozoa and egg fecundity. It appears that astaxanthin may also be the precursor of vitamin A. However, the transformation of asthaxanthin to vitamin A occurs at a low rate and mainly during dietary deprivation of vitamin A.

BROODSTOCK NUTRITION

Reproduction represents an important biological function that requires the synthesis of sexual products from dietary nutrients. Successful reproduction is therefore dependent upon diets which meet the specific requirements of maturing fish. Information on the nutrient requirements for successful reproduction by fish is limited. Nevertheless, a few short reviews have been published (Fontaine and Oliverau 1963; Hardy 1985; Luquet and Watanabe 1986).

Both quality and quantity of diet affects broodstock reproductive success and subsequent development of offspring. Generally, a variation in nutrient intake causes a change in the chemical composition of eggs, milt and yolk sac fry. Diet also influences the egg quality (color, weight and size). It is also recognized that diets containing adequate levels of essential nutrients reduce the prespawning mortality of mature male and female fish. Recently, Springate et al. (1985) and Knox et al. (1988) reported that female rainbow trout fed a half ration (0.35% body weight per day) showed lower egg production and egg size and altered the composition of eggs (proximate, elemental, amino acid, fatty acid and enzyme). Despite these changes, the total hatchability was not significantly influenced. It appears that the supply of essential nutrients in the diet is more critical in broodstock diets; however, the feeding rate affects the growth rate and fecundity of female fish.

Except for the rainbow trout, the essential fatty acid requirement of most broodstock salmonids has not been established. However, there is sufficient evidence from fatty acid composition of various tissues of various species to indicate that the n-3 type fatty acids are necessary in broodstock diets. Leray et al. (1985) have demonstrated that EFA plays an important role at each stage of ovogenis and EFA is essential for normal spawning and to ensure good hatchability of eggs. A low protein diet has no adverse effect on reproduction if sufficient energy is supplied by the lipid supplement (Watanabe et al. 1985).

Excessive amounts of carbohydrates in broodstock diets may be deleterious, producing abnormally high levels of glycogen in the liver, thus increasing susceptibility to mineral toxicity and infections. The role of trace elements (manganese, iron, zinc and copper) and vitamins (ascorbic acid, vitamin E) has also been demonstrated in reproduction. Although carotenoids are widely distributed in salmonid eggs (Craik and Harvey 1984), their biological role is not clearly defined (Tacon 1981).

NUTRITION AND IMMUNITY

The need for proper diet in preserving good health is often stressed in aquaculture. Recently, Lall (1988) has reviewed pertinent literature on the relationship between nutrition, immunity and infection in finfish and the role of various dietary factors in controlling dieseases.

There are many causes of nutritional deficiencies in an organism which may be independent of adequate food intake. Environmental stress, altered gastrointestinal activity, disease state, physiological needs, drug-induced anorexia, metabolic defects and food contaminants, etc. may all lead to malnutrition. Often it is difficult to diagnose the cause of nutritional deficiencies of fish at various stages of development because the quantitative requirement of nutrients is specified for growth only. In many cases, species, genetic differences, nutrient interactions, nutrient bioavailability and ability of an organism to adapt to food deprivation may alter the magnitude of a specific nutrient deficiency. Certainly it is possible to diagnose a severe deficiency of a nutrient such as ascorbic acid which causes scoliosis; however, a marginal deficiency of one or more nutrients is always difficult to characterize. Morphological signs of nutrient deficiency and toxicity in fish have been summarized by Tacon (1985). Deficiencies or excesses of each of the major dietary components, including protein, fats, total calories, vitamins and trace elements may have profound effects on disease development and survival of the fish, largely due to their effects on host defence mechanisms. Nutritional deficiencies may influence the integrity of skin and epithelial tissues, the composition of tissues and body fluids and reduce mucus secretions predisposing fish to infections.

There are few studies on the relation of nutrition to disease resistance and immune function in fish (Table 5). Evidence exists that certain vitamins, minerals and feed supplements influence the immune response to fish. Reports on the stimulatory effects of large doses of vitamins, especially C and E, upon immune response of experimental rainbow trout are of interest (Blazer and Wolke 1984a, b; Halver and Navarre 1987). However, the practical application of these findings should be carefully evaluated and tested under field (farm or hatchery) conditions with the species in question. It appears that species differences exist. The stimulatory effects of vitamins C and E (Lall et al. 1988; Lall et al. 1989, unpublished results) could not be confirmed in Atlantic salmon. Nutrition information could be best applied more effectively with vaccines and/or chemotherapy in the eradication and treatment of infectious diseases.

DIET AND WATER POLLUTION

The composition, digestibility and physical characteristics of the diet utilized for fish culture may have a significant effect on water quality. The excretion of undigestible matter can be reduced by the manipulation of diet composition. The use of feed ingredients containing high concentrations of ash, fibre, chitin and undigestible carbohydrate results in an increase in the excretion of suspended solids, ammonia and phosphorus. These substances

Table 5. Summary of certain disease and nutrition interactions reported in salmonids.

Nutrient	Dietary level (mg/kg)	Bacterial pathogen	Immune response	Result	Fish species	Reference
Vitamin C	500-2000	*Vibrio anguillarum*	Nonspecific resistance, antibody production	Beneficial	Rainbow trout	Halver and Navarre (1987)
	0-2000	*V. anguillarum*	Nonspecific resistance, antibody production, humoral response and complement system	No beneficial effect	Atlantic salmon	Lall (1988)
	0-2000	*Aeromonas salmonicida*	Same as above	No effect	Atlantic salmon	Lall (1988)
	0-2000	*Yersinia ruckeri*	Same as above	No effect	Atlantic salmon	Lall (1988)
	120	*Y. ruckeri*	Nonspecific resistance Iron binding capacity, Phagocytosis	Decreased no effect	Rainbow trout	Blazer (1982)
Vitamin E	0	*Y. ruckeri*	All aspects of humoral and cellular immunity	Reduced	Rainbow trout	Blazer (1982)
	0-240	*A. salmonicida*	Nonspecific resistance, antibody production, humoral response and complement system	No beneficial effect	Atlantic salmon	Lall (1988)
Pyridoxine[a]	20-40	*V. anguillarum*	Nonspecific resistance	Beneficial	Chinook salmon	Hardy et al. (1979)
Vitamin C, zinc and manganese[b]	+	*Renibacterium salmoninarum*	Nonspecific resistance, antibody production	No beneficial effect	Sockeye salmon	Bell (1984)
Iodine and fluorine	4.5 mg	*R. salmoninarum*	Resistance to natural infection	Beneficial	Atlantic salmon	Lall (1985)

[a] Diet containing 65% protein

[b] Premix supplied following nutrients (mg/kg): L-ascorbic acid (100, 1000, 10,000), zinc (1, 104) and manganese (19.7, 135).

cause eutrophication and consequently lead to oxygen deficits in the effluent water.

Generally, undigested protein or carbohydrate produces suspended solids and increased biochemical oxygen demand. A diet containing a high level of protein or a poor quality protein with a low level of energy supplied from lipid results in an increase in the oxidation of protein. These diets cause higher ammonia excretion from gills and also increase the fecal nitrogen content. The phosphorus output from the fish farms could be controlled by reducing the phosphorus level in the diet, increasing the feed efficiency and limiting the use of feed ingredients supplying excessive levels of phosphorus (Ketola 1985; Sumari 1986; Crampton 1987). Excessive levels of carbohydrates, particularly starch, in the diet cause the growth of fungus in sewage (Henderson and Bromage 1987). Furthermore, diets containing a high level of fat which are not properly retained in the pellet may leach out during the feeding of fish, thus producing a thin film on the water surface. These oils not only cause the water pollution but also affect the gills of fish.

SALMON AND HUMAN HEALTH

Recent evidence of the protective role on n-3 polyunsaturated fatty acids (PUFA) against cardiovascular diseases has resulted in the promotion and increased consumption of fish as human food. The beneficial effects of marine fish oil and fishery products have been attributed to a higher ratio of n-3 to n-6 PUFA in blood and cell membrane lipids. The most important n-3 PUFA is eicosapentaenoic acid (EPA). Although ingestion of n-6 PUFA supplied from plant and lipid sources may depress serum cholesterol, the higher level of arachidonic acid (20:4 n-6) in human tissues may override the normal levels of eicosenoids, thus accentuating certain chronic and acute diseases such as atherosclerosis, thrombosis, arthritis and asthma, etc. Eicosapentaenoic acid has an anti-aggretory potency which is mediated by its competitive inhibition of thrombolic eicosenic thrombaxne. The response may also be attributed to a higher production of other anti-aggretory agents such as the production of prostacyclins.

The consumption of fish and fishery products may also provide a possible nutritional approach to reducing these pathophysiological states. At present, wild salmonids are classified as a medium fat food supplying 4-8% fat (Ackman et al. 1988). Our recent work on the lipid composition of farmed Atlantic salmon showed that fish fed a high energy diet containing herring oil as lipid supplement deposit a high concentration of lipid (12-18%) in their body (Table 6). These diets cause an enrichment of PUFA and a total n-3 PUFA level which reached 2.7 g per 100 g of flesh. Further research on the dietary enrichment of salmonid feeds with marine fish oils rich in n-3 PUFA would promote salmonids as an important seafood in human health and disease prevention.

FISH FEED PROCESSING

Several forms of commercial feeds are produced for salmonids. They are mainly classified as dry and moist feeds. Generally, dry feeds contain 8-10% moisture, whereas the water content of moist feed ranges from 17-40% or more. The feed processing involves both physical processes (grinding, mixing and agglomeration, drying, screening and crumbling, etc.) and chemical process (changes in the chemical properties of starch and protein, etc.). In recent years, significant progress has been made in the production of dry feeds. The introduction of high energy diets for net-pen culture of salmonids has created considerable interest in the extrusion process which is slowly replacing the conventional steam pelleting process.

DRY DIETS

Most of the diets manufactured for feeding salmon and trout utilize either steam pelleting or extrusion processing to produce dry pellets. In the steam pelleting process, moisture, heat and pressure agglomerate the finely ground feed mixture into larger uniform pellets. During the processing, steam is added to the feed in a conditioning chamber where it is mixed with feed to raise moisture to approximately 15-18% and temperature to 70-80°C. Feed is then forced through dies of various size openings and cut to varying lengths. The moisture in pellets are reduced by forcing air over the heated pellets. These pellets could be further crumbled into smaller granules.

Table 6. Total lipid, eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids and total n-3 acids in selected wild and cultured salmonids.

Species	Total lipid (g/100 g)	EPA (20:5 n-3) (g/100 g)	DHA (22:6 n-3) (g/100 g)	Total n-3 (g/100 g)
Atlantic salmon, wild[a]	6.5	0.37	0.69	1.15
Atlantic salmon, cultured[a]	16.1	0.75	1.23	2.72
Rainbow trout, wild[b]	1.8	0.10	0.30	0.39
Rainbow trout, cultured[c]	3.9	0.12	0.50	0.72
Coho salmon, wild[d]	4.4	0.42	0.72	1.17
Pink salmon, wild[b]	4.2	0.46	0.84	1.67

[a] Lall et al. (1989), unpublished results.
[b] Hearn et al. (1987).
[c] Ackman (1988).
[d] Polvi (1989).

Extrusion processing requires more sophisticated equipment and the production cost is high. Much higher levels of temperature, pressure and moisture are applied to the feed mash than in the steam pelleting process. The finely ground feed in the conditioning chamber is heated to 104-148°C with dry steam under pressure to raise moisture to approximately 20-25%. The sudden reduction in pressure as the material squeezes through the die holes at the end of the barrel allows the expansion of water vapor and entrapment of air. The carbohydrate fraction of the diet becomes gelatinized and the air is trapped in the minute pocket of the pellet. These extruded pellets contain more water than steam pellets and also require external drying. Certain changes in diet composition and extrusion processing conditions can produce a floating or slow sinking pellet.

Often, special ingredients or binders are incorporated to prevent pellet disintegration. Wheat gluten, ground wheat and precooked starches (pregelatinized) are used to increase the pellet durability. Selected organic hydrocolloids (carboxy methyl cellulose, guar gum and alginic acid), lignin sulfonate, polymethylcarbamide, sodium and calcium bentonite, molasses and whey, etc. are also incorporated into feed formulas as binders.

Dry pellets have several advantages because they ensure continuous availability and uniformity of feed, ease of transport, storage and feeding. Furthermore, the nutrient loss by leaching is minimal, water quality is not seriously affected and the risk of feeding improperly processed trash feed is greatly reduced. The feed can be adapted physically to the requirements of fish by varying size, which gives improved utilization at every stage of growth.

MOIST FEEDS

The processing and production of moist feeds show wide variations. Moist pellets contain variable amounts of fish tissue (ground whole fish, fish and crustacean waste, liver, slaughterhouse by-products, etc.) and/or fish silage. Dry ingredients (fish meal, whey, wheat by-products), vitamin and mineral supplements and hydrocolloidal binding agent (e.g. guar gum, algenates, carboxy methyl cellulose and gelatinized starch, etc.). The diet is either cold pelleted, extruded through meat grinders or more elaborate types of cold grinders and extruders. The raw fish and fishery by-products must be pasteurized to destroy pathogens and the thiaminase enzyme found in fish tissues. Improper and long-term storage of these diets can adversely affect the stability of vitamins, cause oxidation of lipid and an increase in bacterial and fungal contamination.

Often, the supplementation of humectants (propylene glycol and sodium chloride) which lower water activity to prevent bacterial growth and fungistats (propionic and sorbic acid) to retard mold growth is required in these diets. The high moisture enhances the loss of vitamin C. Approximately 90% of the ethyl cellulose coated ascorbic acid is lost in moist feed (25-40% water) within 48 hr when stored at 5°C (Lall 1986, unpub. data).

Salmonids prefer moist pellets as compared to steam pellet and extruded feeds. In areas where a significant amount of fishery by-products is available at relatively low cost, these diets have certain advantages. It has been also found that acceptability and utilization of moist pellet may cause feed waste and water pollution.

REFERENCES

Ackman, R. G., S. M. Polvi, R. L. Saunders, and S. P. Lall. 1988. Lipid composition of market size fish and human health issues, p. 443-448. In Proc. Aquaculture Int'l. Congress and Exposition, Vancouver, Canada, September 6-9, 1988.

Asgard, T. 1988. Nutritional value of animal protein sources for salmonids, p. 411-418. In Proc. Aquaculture Int'l. Congress and Exposition, Vancouver, Canada, September 6-9, 1988.

Bell, G. R., D. A. Higgs, and G. S. Traxler. 1984. The effect of dietary ascorbate, zinc, and manganese on the development of experimentally induced bacterial kidney disease in sockeye salmon (*Oncorhynchus nerka*). Aquaculture 36: 293-311.

Blazer, V. S. 1982. Effects of marginal deficiencies of ascorbic acid and alpha tocopherol on the natural resistance and immune response of rainbow trout (*Salmo gairdneri*). Univ. Microfilms International, Ann Arbour, Michigan 1848: 113 p.

Blazer, V. S., and R. E. Wolke. 1984a. The effects of α-tocopherol on the immune response and non-specific resistance factors of rainbow trout (*Salmo gairdneri* Richardson). Aquaculture 37: 1-9.

Blazer, V. S., and R. E. Wolke. 1984b. Effect of diet on the immune response of rainbow trout (*Salmo gairdneri*). Can. J. Fish. Aquat. Sci. 41: 1244-1247.

Castell, J. D., R. O. Sinnhuber, J. H. Wales, and D. J. Lee. 1972. Essential fatty acids in the diet of rainbow trout (*Salmo gairdneri*): growth, feed conversion and some gross deficiency symptoms. J. Nutrit. 102: 77-86.

Cho, C. Y., and S. Kaushik. 1985. Effects of protein intake on metabolizable and net energy values of fish diets, p. 95-117. In C. B. Cowey, A. B. Mackie and J. G. Bell (ed.) Nutrition and feeding in fish. Academic Press, London.

Cowey, C. B., A. B. Mackie, and J. G. Bell. 1985. Nutrition and feeding in fish. Academic Press, London.

Craik, J. C. A., and S. M. Harvey. 1984. Biochemical changes associated with over-ripening of the eggs of rainbow trout (*Salmo gairdneri* Richardson). Aquaculture 37: 347-357.

Crampton, V. 1987. How to control phosphorous levels. Fish Farmer 10: 38-39.

Embody, G. C., and M. Gordon. 1924. A comparative study of natural and artificial foods of brook trout. Trans. Am. Fish. Soc. 54: 185-200.

Fontaine, M., and M. Oliverau. 1963. Nutrition et sexualité chez les poissons, p. 125-152. Dans La nutrition chez les poecilothermes. Centre National de la Recherche Scientifique, Paris.

Halver, J. E. 1989. The vitamins, p. 31-109. In J. E. Halver (ed.) Fish nutrition. Academic Press, San Diego.

Halver, J. E., and O. Navarro. 1987. Disease resistance and humoral antibody production in rainbow trout fed high levels of vitamin C. Int'l. Symposium on

Feeding and Nutrition in Fish, Bergen, August 23-27, 1987 (Abs.).

Hardy, R. W. 1985. Salmonid broodstock nutrition, p. 98-109. In R. Iwamoto and S. Sower (ed.) Salmonid reproduction. Int'l. Symposium, Washington Sea Grant Program, Univ. Washington, Seattle.

Hardy, R. W. 1989. Diet preparation, p. 475-548. In J. E. Halver (ed.) Fish nutrition. Academic Press, San Diego.

Hardy, R. W., J. E. Halver, and E. L. Brannon. 1979. Effect of dietary protein level on the pyridoxine requirement and disease resistance of chinook salmon, p. 253-260. In Proc. World Symposium on Finfish Nutrition and Feed Technology, Hamburg, 20-23 June 1978, Vol. I, H. Heenemann GmbH & Co., Berlin.

Hearn, T. L., S. A. Sgoutas, J. A. Hearn, and D. S. Sgoutas. 1987. Polyunsaturated fatty acids and fat in fish flesh for selecting species for health benefits. J. Food Sci. 52: 1209-1211.

Henderson, P., and N. Bromage. 1987. Diets curb pollution. Fish Farmer 10: 39.

Higgs, D. A., J. R. McBride, B. S. Dosanjh, W. C. Clarke, C. Archdekin and A.-M. Hammons. 1988. Nutritive value of plant protein sources for fish with special emphasis on canola products, p. 427-435. In Proc. Aquaculture Int'l. Congress and Exposition, Vancouver, Canada, September 6-9, 1988.

Kanemitsu, T., and H. Aoe. 1958. On the studies of carotenoids of the salmon - II Determination of muscle pigment. Bull. J. Soc. Sci. Fish. 24: 555-559.

Ketola, H. G. 1985. Mineral nutrition: effects of phosphorous in trout and salmon feeds on water pollution, p. 465-473. In C. B. Cowey, A. M. Mackie and J. G. Bell (ed.) Nutrition and feeding in fish. Academic Press, London.

Knox, D., N. R. Bromage, C. B. Cowey and J. R. C. Springate. 1988. The effect of broodstock ration size on the composition of rainbow trout eggs (*Salmo gairdneri*). Aquaculture 69: 93-104.

Kotik, L. V., . Tolokonnikov, G. Yu, and V. N. Dubrovin. 1979. The effect of krill meal additions to feeds of muscle pigmentation in the rainbow trout (*Salmo gairdneri*). J. Ichthyol. 19: 114-123.

Lall, S. P. 1987. Fish silage as feed for salmon and trout, p. 56-63. In Proc. of the Fish Silage Workshop, Univ. Sainte-Anne, Nova Scotia, Canada, June 16-17, 1987.

Lall, S. P. 1988. Disease control through nutrition, p. 607-612. In Proc. Aquaculture Int'l. Congress and Exposition, Vancouver, Canada, September 6-9, 1988.

Lall, S. P. 1989. The minerals, p. 219-257. In J. E. Halver (ed.) Fish nutrition. Academic Press, Dan Diego.

Lall, S. P., W. D. Paterson, J. A. Hines, and N. J. Adams. 1985. Control of bacterial kidney disease in Atlantic salmon, *Salmo salar* L., by dietary modification. J. Fish Diseases 8: 113-124.

Leray, C., G. Nonnotte, P. Roubaud, and C. Leger. 1986. Incidence of (n-3)-essential fatty acid deficiency in trout reproductive processes. Reprod. Nutrit. Develop. 25: 567-581.

Luquet, P., and T. Watanabe. 1986. Interaction "nutrition-reproduction" in fish. Fish Physiol. Biochem. 2: 121-129.

McLaren, B. A., E. Keller, D. J. O'Donnell, and C. A. Ellehjem. 1947. The nutrition of rainbow trout. I. Studies of vitamin requirements. Arch. Biochem. 15: 169-178.

National Research Council. 1981. Nutritional requirements of coldwater fishes. Nat. Acad. Sci., Washington, DC.

Phillips, A. M., Jr., H. A. Podoliak, H. A. Poston, D. L. Livingston, H. E. Brooks, E. E. Pyle, and G. L. Hammer. 1964. Dry concentrates as complete fish foods, p.

47-54. In The nutrition of trout. Cortland Hatchery Rep. 32 for the year 1983. Fish. Res. Bull. 27, New York State Conservation Dept., Albany, NY.

Polvi, S. 1989. Diet and bioavailability of Omega-3 fatty acids in salmonids. M.Sc. Thesis, Tech. Univ. of Nova Scotia, Canada.

Saito, A. 1969. Color in raw and cooked Atlantic salmon (*Salmo salar*). J. Fish. Res. Board Can. 26: 2234.

Schiedt, K., F. J. Leuenberger and M. Vecchi. 1981. Natural occurrence of enantiomeric and meso-astaxanthin 5. Ex wild salmon (*Salmo salar* and *oncorhynchus*). Helv. Chim. Acta 64: 449-457.

Skrede, G., and T. Storebakken. 1986. Characteristics of color in raw, baked and smoked wild and pen-reared Atlantic salmon. J. Food Sci. 51: 804-806.

Smith, R. R. 1989. Nutritional energetics, p. 1-29. In J. E. Halver (ed.) Fish nutrition. Academic Press, San Diego.

Springate, J., N. B. Bromage, and P. R. Cumarantunga. 1985. The effects of different ration on fecundity and egg quality in the rainbow trout (*Salmo gairdneri*), p. 371-393. In C. B. Cowie, A. M. Mackie and J. G. Bell (ed.) Nutrition and feeding in fish. Academic Press, London.

Storebakken, T., P. Foss, K. Schiedt, E. Austreng, S. Liggen-Jensen, and U. Mantz. 1987. Carotenoids in diets for salmonids. IV. Pigmentation of Atlantic salmon with astaxanthin, astaxanthin dipalmitate and canthaxanthin. Aquaculture 65: 279-292.

Sumari, O. 1986. Feed and waste water in aquaculture, p. 230-254. In A. Grimaldi and J. Rosenthal (ed.) Trends and problems in aquaculture development. Proc. 2nd Int'l. Conf. on Aquafarming, Fiere di Verona, Italy.

Tacon, A. G. T. 1981. Speculative review of possible carotenoia function in fish. Prog. Fish Cult. 43: 205-208.

Tacon, A. G. T. 1985. Nutritional pathology. U.N.D.P.-F.A.C., ADCP/REP/85/22, Rome.

Takeuchi, T., T. Watanabe, and T. Nose. 1979. Requirement for essential fatty acid of chum salmon (*Oncorhynchus keta*) in freshwater environment. Bull. Jap. Soc. Sci. Fish. 45: 1319-1323.

Torrissen, K. R., R. W. Hardy, and K. D. Shearer. 1989. Pigmentation of salmonids - carotenoid deposition and metabolism. CRC Press, Rev. in Aquat. Sci. 1: 209-225.

Torrissen, K. R., and O. J. Torrissen. 1985. Sexual maturation: effect on protease activities and carotenoid levels in Atlantic salmon (*Salmo salar*). Aquaculture 50: 113-122.

Torrissen, O. J., and O. R. Braekkan. 1979. The utilization of astaxanthin-forms by rainbow trout (*Salmo gairdneri*), p. 378-382. In Proc. World Symposium on Finfish Nutrition and Fishfeed Technology, Hamburg, June 22-23, 1978, Vol. II. H. Heenemann GmbH and Co., Berlin.

Watanabe, T. 1974. Requirement of rainbow trout for essential fatty acids. Bull. Jap. Soc. Sci. Fish. 40: 493-499.

Watanabe, T. 1985. Importance of the study of broodstock nutrition for further development of aquaculture, p. 395-414. In C. B. Cowey, A. M. Mackie and J. G. Bell (ed.) Nutrition and feeding in fish. Academic Press Inc., London.

Watanabe, T. 1988. Nutritional value of animal and plant lipid sources for fish, p. 437-442. In Proc. Aquaculture Int'l. Congress and Exposition, Vancouver, Canada, September 6-9, 1988.

Wilson, R. P., and J. E. Halver. 1986. Protein and amino acid requirements of fishes. Ann. Rev. Nutrit. 6: 225-244.

Yu, T. C., and R. O. Sinnhuber. 1979. Effect of dietary W3 and W6 fatty acids on growth and feed conversion efficiency of coho salmon (*Oncorhynchus kisutch*). Aquaculture 16: 31-38.

FISH MEAL - A LIMITED RESOURCE?

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ABSTRACT

Smith, P. and J. S. Kilpatrick. 1991. Fish meal - a limited resource? p. 125-132. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

The nutritional specification of salmon feed has improved over the last two decades, with higher levels of protein, oil and metabolisable energy. At the same time, there has been a tendency towards higher levels of fish meal inclusion and use of 'superior quality' fish meals.

A close nutritional fit with the requirements of salmon and a relatively palatability will ensure continued use at a high level. This should not cause a supply problem in the foreseeable future as the demand from intensive aquaculture, increasing from 529,000 t to 884,000 t over the next 5 yr, still represents only 13.3% of the current supply. However, it is essential to develop methods of chemical analysis for assessment of fish meal quality which correlate closely with biological performance of salmon. A number of analytical techniques are indicated, with comparison of values for standard and special quality meals. There is a trend for fish meal producers to upgrade their methods of handling and the production process in order to improve the quality of their product and achieve a premium price. The level of such a premium must be related to economic improvement in salmon production and current indications are that this premium should not be greater than 10% over the standard meal to ensure a fair distribution of the added value between suppliers and salmon producers.

RÉSUMÉ

Smith, P. and J. S. Kilpatrick. 1991. Fish meal - a limited resource? p. 125-132. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, Feburary 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

Le contenu nutritionnel des aliments du saumon s'est amélioré au cours des deux dernières décennies, ces aliments étant maintenant plus riches en protéines, huile et énergie métabolisable. En même temps, on s'est orienté vers l'adjonction accure de farine de poisson et vers la production de farine de poisson de qualité 'supérieure'.

Compte tenu de leur appétabilité relative et de leur étroite correspondance avec les besoins nutritifs du saumon, ces aliments continueront d'être très utilisés. Cela ne devrait pas poser de problème de pénurie dans un avenir proche, la demande provenant de l'aquiculture intensive - qui passera de 529 000 t à 884 000 t au cours des cinq prochaines années - ne représentant seulement que 13,3% de l'offre actuelle. Toutefois, il est essentiel de concevoir des méthodes d'analyse chimique permettant d'établir un rapport étroit entre la qualité de la farine de poisson par rapport et le rendement biologique du saumon. On présente un certain nombre de techniques d'analyse, en comparant les valeurs de la farine de poisson

ordinaire et de la farine de poisson de qualité 'supérieure'. Les producteurs de farine de poisson ont tendance à améliorer leurs méthodes de manutention et leur processus de production pour accroître la qualité de leur produit et en obtenir un prix supérieur. Ce prix doit être en rapport avec l'amélioration économique obtenue dans la production du saumon; selon les indicateurs actuels, le prix du produit de qualité supérieure ne devriat pas être supérieur de 10% à celui du prix de la farine ordinaire, pour que la valeur ajoutée soit répartie équitablement entre les foumisseurs de farine et les producteurs de saumon.

INTRODUCTION

In the past two decades, salmon feeds have evolved, first with increasing protein to 44-45% and oil content to 13-14% with the application of fat coating techniques in the 1970's, and then in the early 1980's, the introduction of extrusion technology to further increase metabolizable energy by gelatinization of whole wheat starch and further increase oil content to as much as 23% (Table 1). At the same time, there has been a tendency towards ever increasing fish meal levels and, most recently, the use of special quality fish meals, often referred to as LT meals (low temperature processed).

Table 1. Composition of salmon feeds, 1965-85.

	1965	1975	1985
Protein %	38	44	45
Fat %	6	13	23
CBH %	29	23	15
Ash %	15	10	7
Moisture %	12	10	10
Metabolizable energy	10.5	13.5	17.5
FCR	2.0-2.5	1.5-2.0	1.0-1.5

While it appears that this trend towards increasing diet specification and cost appears at variance with one's normal expectation of technical and technological progress towards greater performance for lower cost, it should be realized that these developments have been driven by European experience, where salmon diet development was a natural extension of the experience with rainbow trout formulation and this progression towards higher specification recognized differences between the needs of rainbow trout and Atlantic salmon and was indeed rewarded with improved economic performance for producers, despite the increased cost of the feed.

ALTERNATIVES

The move to higher levels of fish meal, in excess of 50% in some cases, may seem curious at a time when the general trend in other livestock formulations is to find ways to reduce costs by substituting the more expensive protein sources with cheaper ones. So too with salmonids, there has been much research to find substitutes from vegetable protein sources such as soya meal, corn gluten, canola meal, etc., single-cell proteins of varying origin such as yeasts, bacteria, fungi, algae and a variety of animal by-products such as meat meal, poultry meal, feather meal and blood meal, all with varying and often limited success. This is not to say, however, that a proportion of the fish meal cannot be substituted with careful formulation, which most often will combine several protein sources, to achieve a balance of nutrients suited to the needs of the species, and taking due account of any inclusion limitations which may be imposed by antinutritional or palatability factors. However, it is clear that it is far easier to substitute the first 10% of the fish meal in a salmon diet than the next and it gets progressively more difficult as the level diminishes.

NUTRITIONAL VALUE

What fish meal offers is a relatively close fit to the nutritional needs of salmonids in terms of amino acid and fatty acid composition. Fish meals generally supply adequate levels of essential amino acids, while cereal proteins are frequently deficient in lysine and many other substitute proteins of vegetable, microbial or animal origin are deficient in methionine. Also, fish oils generally have a larger quantity of polyunsaturated fatty acids, particularly of the essential longer chain omega 3 variety, than either vegetable or animal oils. Additionally, suitability of one or other protein source goes beyond nutrient composition. The nutritional value of a diet which is not consumed is zero, no matter what its composition. Good quality assumed, fish meal has been shown consistently to have a relatively high palatability to salmon. This latter characteristic cannot be overstated as lack of palatability, as opposed to nutritional composition, limits the use of many potential substitute protein sources.

SUPPLY

It seems likely, then, that fish meal will continue to figure prominently in salmon diets for some time to come and it is instructive, therefore, to consider the supply demand situation.

The world fishery resource was 92 million t in 1986, a year for which comparable statistics are available. Of this, 29% was industrial species for reduction (Fig. 1 - this does not include fish processing by-product reduction). From this resource, the total world production by major producing countries is shown (Fig. 2). A large proportion of production is used in the country of origin, particularly noticeable in Japan, USSR, USA and Norway, leaving only about half of production for export, with Chile being by far the largest exporter (Fig. 3).

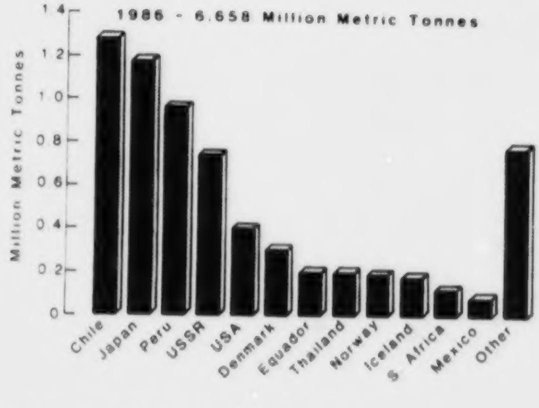

Fig. 2. World fish meal production.

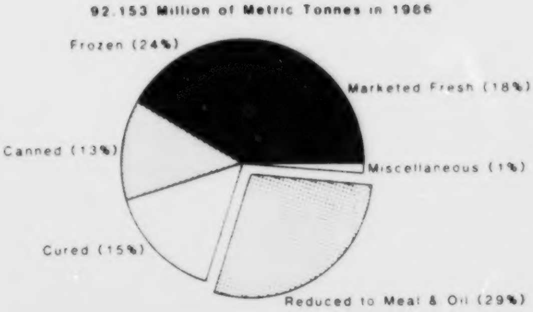

Fig. 1. Disposition of world fishery landings.

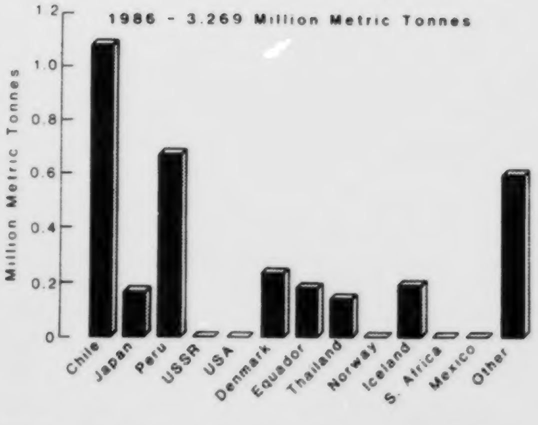

Fig. 3. World fish meal exports.

DEMAND

Aquaculture is growing rapidly throughout the world. It is the intensively reared high value species of finfish and crustaceans which have greatest demand on the fish meal resource. Commercial aquaculture production in 1987 was 1.06 million metric tonnes (MT) and may be expected to increase to 1.62 million MT by 1992, with the biggest increases coming from salmon and shrimp (Fig. 4). From typical inclusion, levels of fish meal in commercial diets for these species, the demand for aquaculture is of the order of 529,000 MT (Fig. 5b), which is only about 7.9% of the resource, increasing to 13.3% by 1992 (Fig. 5a). As large as this growth rate seems, the absolute quantities involved have to be considered in relation to the total world picture in the supply/demand relationship of the major protein sources. Thus, on the supply side, fish meal is dwarfed by vegetable protein commodities, particularly soyabean meal (Fig. 6), and on the demand side the commercial aquaculture species tonnage is very small, and is likely to remain so for many years to come, compared to other livestock production such as poultry, pig and beef (Fig. 7).

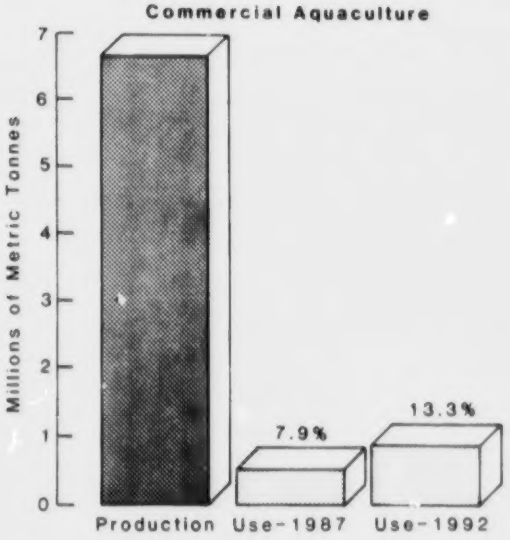

Fig. 5a. Fish meal use.

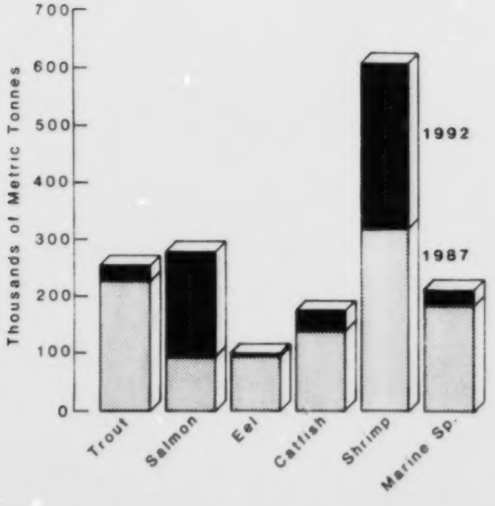

Fig. 4. Commercial aquaculture production.

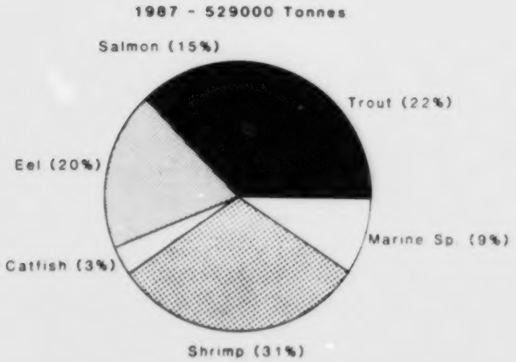

Fig. 5b. Fish meal use - commercial aquaculture.

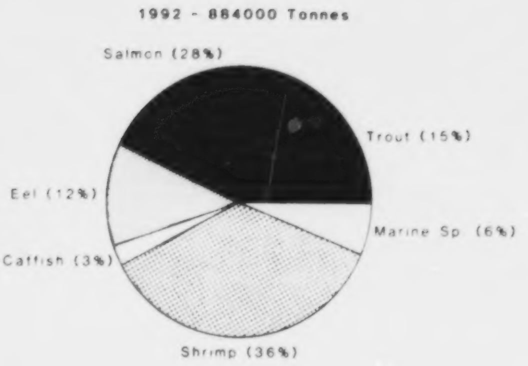

Fig. 5c. Fish meal use - commercial aquaculture.

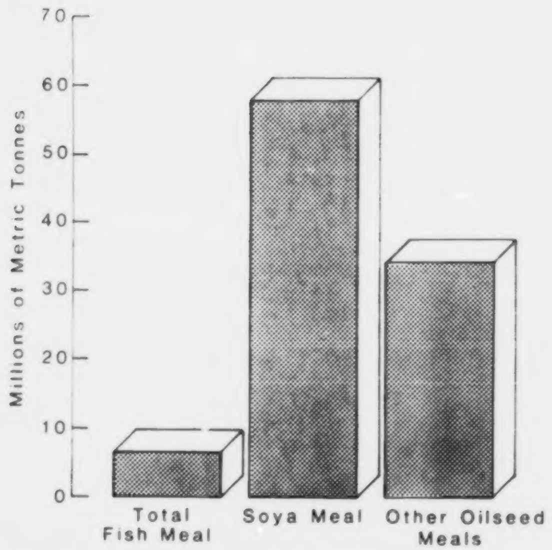

Fig. 6. Major protein sources 1986.

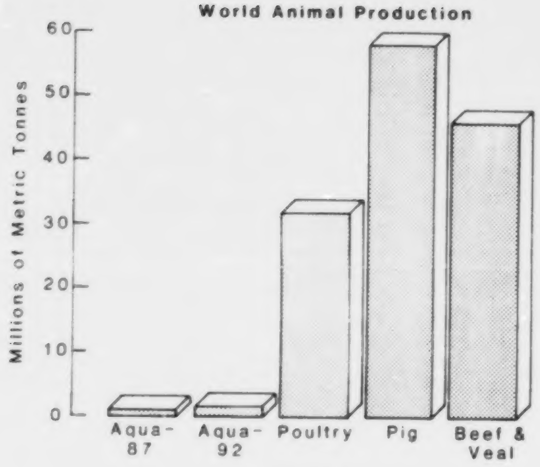

Fig. 7. Competitive uses of fish meal.

PRICES

Prices for protein commodities tend to be closely related; thus, for example, soya and fish meals usually move in the same direction (Fig. 8). With linear programming techniques widely used to optimize diets for livestock, any tendency for a major shift in the relationship would result in some compensation in demand. A reduction of 0.5% in the inclusion level of fish meal in poultry diets would be equal to the total increase in demand for fish meal for aquaculture in the next 5 years. Given the magnitude of both supply and demand for protein commodities, including fish meal and assuming relative stability on the supply side, it is unlikely that aquaculture will have difficulty in meeting its needs in the foreseeable future or that it will exert much influence on the price of proteins.

QUALITY ISSUES

On the other hand, it is essential to be aware of the different qualities of fish meal available today. Not all fish meals perform equally in the diets of salmon, either because of

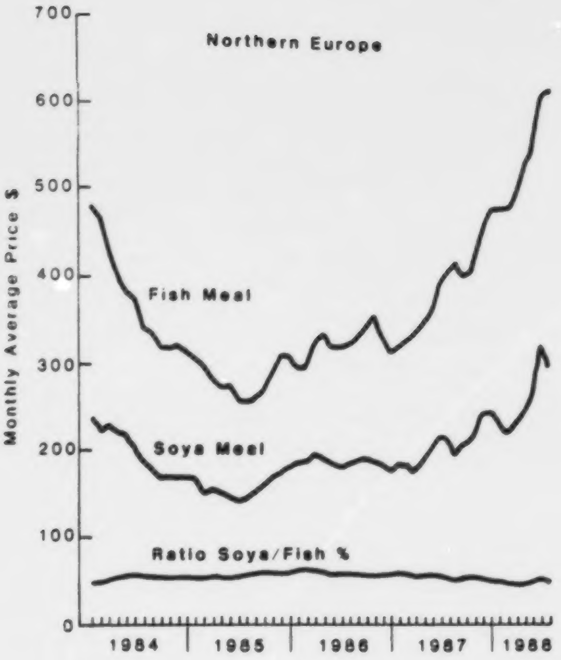

Fig. 8. Prices of fish meal and soyabean meal.

differences in nutrient availability, or again differences in palatability, which can have a profound effect on performance. Differences in quality may relate to species of the raw material, method and length of storage before processing or processing technology, particularly the temperature used during the drying process. One must be careful not to judge quality by geography of supply alone, for there are good and poor fish meals from all regions. Certainly, Norway has led the way in differentiating qualities but there are now a number of plants in other countries such as Denmark, Iceland and Chile where progress has been made in producing 'superior quality meals.' The problem we face, however, is to find routine and cost effective methods of measuring quality.

Methods of assessing quality fall into three categories: a) physical inspection; b) chemical analysis; and c) biological measurement (Table 2). The meal should always be free from contamination, even in color and of uniform particle size, free from damp spots or warm areas and without pungent or rancid odors.

Table 2. Quality control criteria.

1) Physical inspection
    - Color
    - Texture
    - Odor
    - Microscopic analysis

2) Chemical analysis
    - Proximate analysis
    - Amino acid analysis
    - Available lysine
    - Digestibility-modified torry
    - TVN of raw material
    - Titration value
    - NH3-N
    - Total biogenic amines

3) Biological measurement
    - Chick gizzard erosion score
    - Chick feeding trial
    - Mink feeding trial
    - Fish feeding trial

Microscopic analysis may give an indication of drying conditions; there should be no evidence of burning. In the second category, tests such as amino acid analysis and pepsin digestibility will say something of the nutritional value, while others such as TVN of the raw material, free fatty acids, biogenic amines will say something about the freshness of the raw material or the degree of damage during processing.

Some comparisons of analysis for standard and 'superior quality' meals are shown in Table 3a. Norwegian meals have been differentiated mainly on the TVN of the raw material, ammonia N and pepsin digestibility (dilute pepsin method). This lead has been followed by other countries, e.g. Chile. An indication of the freshness of the raw materials used can also be obtained from measurement of biogenic amines as, for example, shown in the analysis of two qualities of Danish meal (Table 3b). It is clear that freshness of the raw material is at least as important as processing temperature. Changes in the raw material occur very quickly, so it is essential that it is processed as soon after catch as possible.

Table 3a. Quality description of Norwegian special quality fish meals.

	NorSea Mink	Norse-LT94
Raw material		
TVN mg/100 g	<90	<50
Chemical composition (g/100 g of meal)		
Moisture	5-10	5-10
Protein min	70	68
Fat max		11.5
Ash-salt max	14	14
Salt (NaCl) max	3	3
Quality criteria		
NH_3, g^{-2}/100 g max	18	16
Pepsin digestibility (Torry) max	-	94

Such methods of chemical analysis are very useful, but it is the assessment of performance in the target animal which can provide the most interesting and directly applicable evaluation. Unfortunately, such tests take too much time and expense to be of use on a routine basis. It is essential, therefore, to find laboratory methods of quality assessment such as those in category 2 (Table 2) which can be undertaken quickly and within reasonable cost and correlate well with biological assessment in the target animal, in this case salmon.

We are now busy establishing both the best criteria and monitoring programs for use in both Atlantic salmon and Pacific salmon. What we are looking for are sources of supply which consistently produce good results in commercial feeds, manifest by growth, food conversion ratio, fitness and survival and impact on the quality of the end product. It is equally important that we quantify the benefits of 'superior quality meals' in economic terms to the salmon producer, for at the end of the day, the farmer must expect an economic improvement at least equal to and preferably beyond the premium charged for the higher quality product.

Table 3b. Danish fish meals actual analysis.

	Standard	Special
TVN, mgN/100 g	301	134
Titration value	114	66
FFA oil	21	
14		
Biogenic amines, µMol/g		
Putrescine	6.1	2.5
Tyramine	4.0	1.8
Cadaverine	11.7	6.4
Histamine	2.0	1.0
Agmatine	1.5	1.5
Phenethylamine	0.7	0.3
Spermidine	0.3	0.1
Tryptamine	0.6	Tr

CONCLUSION

The use of fish meal in salmon diets at relatively high levels is likely to continue and the supply appears to be assured over the foreseeable future. However, it is in the best interest of fish meal producers to upgrade their processing technology and methods of handling, as they will create demand from aquaculture specifically for their products at a premium price. At the same time, all the indications thus far suggest that it is unreasonable of such suppliers to expect much more than a 5-10% premium, for only then is the added value likely to be fairly distributed between suppliers and salmon producers.

There are no statistics available to show what proportion of total fish meal production is of 'superior quality' at this time, but our own evaluations suggest that the rate of improvement and upgrading of production plants world wide will at least equal the increasing demand for aquaculture and ensure not only the future availability of the required quantity, but also of the required quality. It is then up to fish feed manufacturers to put in place a sufficiently high standard of specification, inspection and quality control to ensure the best possible deal for salmon producers.

RECENT DEVELOPMENTS IN SMOLT RESEARCH

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ABSTRACT

Clarke, W. C. 1991. Recent developments in smolt research, p. 133-139. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

One of the main developments in smolt rearing has been a reduction in the length of the production cycle through the use of elevated temperatures and photoperiod control. The technique of off-season transfer of salmon to seawater has been developed to avoid extreme water temperatures during summer and to extend the harvest season. Net pens in fresh water have been adopted as a means of reducing smolt production costs.

RÉSUMÉ

Clarke, W. C. 1991. Recent developments in smolt research, p. 133-139. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

Le raccourcissement de la durée du cycle de production, grâce à l'élévation des températures et à la régulation photopériodique, a été un des plus grands progrès réalisés dans l'élevage des saumoneaux. La technique de transfert hors saison du saumon à la mer a été conçue pour éviter les températures extrêmes de l'été et prolonger la saison de récolte. Par ailleurs, l'utilisation d'enclos en filets placés en eau douce a permis de réduire les coûts de production des saumoneaux.

INTRODUCTION

The growth of salmon farming has often been limited in its initial stages by the availability of high quality smolts. Once smolt producing capacity is adequate to meet demand, there is increased emphasis on improving the efficiency of existing facilities and on developing new and innovative strategies for smolt production in order to remain competitive. The greatest improvement in efficiency of smolt production has been obtained by reducing the rearing time. Smolt age has been reduced from 2+ to 1+ for Atlantic salmon (*Salmo salar*) and from 1+ to 0+ for coho salmon (*Oncorhynchus kisutch*). This has been achieved largely by improvements in the hatchery environment, particularly through control of temperature and photoperiod. This paper reviews developments in our knowledge of the role played by these two important environmental factors controlling growth and smolting. Also, recent innovations in smolt production such as off-season transfers to seawater and use of net pens for freshwater rearing will be discussed.

TEMPERATURE

Hatcheries with unheated water have usually produced 2-yr-old smolts of Atlantic salmon because this species has a relatively low growth rate during the freshwater stage when compared with other salmonids (Gjedrem and Gunnes 1978; Refstie 1983). Although only a small volume of heated water is required to accelerate egg incubation, temperatures of 10-14°C are required for Atlantic salmon fry to start feeding successfully (Saunders 1986). Thus, if the time of hatching is advanced significantly, substantial volumes of heated water are required to ensure that fry begin to feed and grow. Atlantic salmon commonly exhibit bimodality in growth and smolting under hatchery conditions (Thorpe 1977; Bailey et al. 1980; Thorpe et al. 1982). The parr in the upper size mode during autumn develop into smolts during the following spring. A higher growth rate during the first spring and summer results in a greater proportion of fish exceeding the size threshold for entering the upper modal size group (Kristinsson et al. 1985). Temperature conditions during mid to late summer are a major factor influencing entry into the upper modal group (Adams and Thorpe 1989; Thorpe et al. 1989). Thus, many hatcheries are now raising water temperature to increase their production of 1-yr smolts. This is accomplished through the use of industrial cooling water, geothermal water and heat pumps (Peterson 1973; Johnston and Saunders 1981; Kittelsen and Gjedrem 1981; Isaksson 1985; Saunders 1986).

The freshwater phase of the coho salmon life cycle is usually at least 1 yr, although hatcheries using elevated water temperatures for egg incubation and fry rearing are able to produce 0-age smolts (Novotny 1975; Brannon et al. 1982; Clarke 1988). The shorter production cycle for 0-age smolts eliminates the problem of overlapping year-classes in the hatchery and allows the level of smolt production to be adjusted more rapidly to accommodate changes in market demand. However, the quality of smolts produced has been variable, causing many fish to become "stunts" in seawater (Clarke and Nagahama 1977; Folmar et al. 1982; Mahnken and Waknitz 1979; Nishioka et al. 1982; Saxton et al. 1983). It is now recognized that inappropriate conditions of temperature and photoperiod contributed to this variability. Clarke and Shelbourn (1989) investigated the temperature requirements for producing 0-age smolts. They concluded that the minimum freshwater rearing temperature for 0-age smolts is 8°C and that much larger and more uniform smolts were produced at 10-14°C.

PHOTOPERIOD

The annual photoperiod cycle is one of the main environmental cues which synchronizes the seasonal cycles of growth and smolting in many juvenile salmonids (Saunders and Henderson 1970; Clarke et al. 1978; Folmar and Dickhoff 1980; Wedemeyer et al. 1980; Zaugg 1981; Eriksson and Lundqvist 1982; Hoar 1988; Villarreal et al. 1988).

Photoperiod control of smolting has been most intensively studied in coho salmon. Clarke and Shelbourn (1986) demonstrated that photoperiod phase at the time of first feeding influences growth and smolting of juvenile coho. In their experiment, coho fry which were start-fed under December or January photoperiod phase grew more rapidly and uniformly than did those which were start-fed under February photoperiod. This explains much of the variability seen in commercial hatcheries attempting to produce 0-

age coho smolts because spawning date and temperature at which eggs are incubated can change the date of emergence considerably. It has been shown by means of constant photoperiods during the first 2 mo after start-feeding that the effect of photoperiod phase on smolting of coho is a function of initial daylength (Clarke et al. 1989). Fry held under 9.5 hr daylength for 2 mo and then under simulated natural photoperiod for 4 mo grew more rapidly and uniformly both in fresh and in salt water than did those held initially under 14.5 hr daylength. Thorarensen and Clarke (1989) used a two-stage photoperiod experiment to study the mechanisms by which coho salmon measure daylength. They showed that fry exposed to short-day photoperiods (6L:18D or 10L:14D) for 2 mo and then to long-day photoperiod (16L:8D) grew rapidly and adapted readily to seawater. Fry exposed initially to short-day photoperiod and then held under a skeleton photoperiod (9L:6D:1L:8D) grew slightly less than those on the complete long-day photoperiod (16L:8D) but significantly better than those kept on a short-day final photoperiod (10L:14D) having the same number of hours of daylight. These results are consistent with the hypothesis that coho salmon measure daylength not by number of hours of daylight but by the time during the day when light is experienced. Coho fry are very sensitive to low intensity light at night during the priming period; exposure to night illumination at intensities of 0.0001-0.05 lux inhibited subsequent growth and seawater adaptability (Thorarensen et al. 1989). The daylength which must be exceeded to obtain a long-day response is termed the 'critical daylength.' A recent experiment has demonstrated that the critical daylength for coho fry during the 2-mo priming period is between 11.5 and 12 hr (Clarke, unpubl. data). Thus, for production of 0-age coho smolts, the daylength should be kept below this critical daylength for 2 mo from first feeding.

Chinook salmon (*O. tshawytscha*) have two major freshwater life history patterns. Juvenile "ocean-type" chinook enter the sea as underyearlings while "stream-type" juveniles spend at least 1 yr in fresh water prior to smolting (Healey 1983). Stream-type chinook show the same response to photoperiod as do coho; when primed for 2 mo under short-day photoperiod and then exposed to long-day, they develop as 0-age smolts. However, if they are exposed initially to long-day photoperiod, growth is slower and they fail to attain full seawater adaptability (Clarke et al. 1989).

As with coho, masu salmon (*O. masou*) normally reside in fresh water for a year before smolting. However, hatchery-reared masu can be induced to become 0-age smolts if they are pretreated with short-day photoperiod and then exposed to long-day photoperiod (Okumoto et al. 1989).

Atlantic salmon differ from coho and chinook in that fry do not require short-day exposure during the first 2 or 3 mo from first feeding in order to sustain rapid growth during summer (Clarke, unpubl. data). It has been known for some time that long-day treatment can stimulate growth and advance the time of smolting in Atlantic salmon (Komourdjian et al. 1976), but 1-summer-old parr must be given a period of short-day exposure during winter in order to become smolts during the following spring (McCormick et al. 1987; Björnsson et al. 1989). Recently, it has been demonstrated that use of extended daylength during late summer and autumn stimulates growth and allows a greater proportion of parr to enter the upper modal size group (Saunders et al. 1987, 1989). This technique provides a very economical means of increasing the proportion of 1-year smolts since growth acceleration takes place while water temperatures are favorable. High quality smolts can be produced at the usual time in spring, provided that extended daylengths are terminated early in winter (McCormick et al. 1987; Saunders et al. 1989).

In contrast to the above species in which photoperiod controls early growth and smolting, there are a number of salmonids in which seawater adaptation is not governed by photoperiod. Examples are the charrs (*Salvelinus* spp.) (McCormick and Saunders 1987), domesticated rainbow trout (*Salmo gairdneri*) (Johnsson and Clarke 1988) and ocean-type chinook salmon (Clarke et al. 1981; Clarke et al. 1989). These stocks do not undergo a typical smolting process. Instead, seawater adaptability increases proportionally with body size. This characteristic makes them convenient for rearing since growth is essentially continuous at favorable temperatures. Table 1 classifies commonly cultured species according to photoperiod control of juvenile development.

Table 1. Classification of salmonids according to photoperiod control of juvenile development.

Photoperiod controlled	Not photoperiod controlled
Atlantic salmon	Arctic char
Coho salmon	Brook trout
Masu salmon	Domesticated rainbow trout
Sockeye salmon	Ocean-type chinook salmon
Steelhead trout	
Stream-type chinook salmon	

OFF-SEASON TRANSFERS

Another new strategy in smolt production is transfer to seawater cages at times other than the normal spring and early summer period. Off-season transfers can be used to avoid seasonal temperature extremes or algae blooms and to spread the harvest season. They were used first in coho salmon farming as a means of avoiding high water temperatures during summer. Harache et al. (1980) found that 1-summer-old coho larger than 170 mm fork length in September or 210 mm by late December could be transferred successfully to 35 o/oo seawater in Brittany. This seasonally increasing minimum size limit is required in order to avoid cessation of growth and parr reversion (Folmar et al. 1982; Mahnken et al. 1982). This limitation to the use of off-season transfers does not apply to salmonids such as domesticated rainbow trout which do not undergo a typical smolting process. Accordingly, they are considerably more flexible with respect to time of seawater entry, provided that temperatures are favorable. In future, it may be possible to breed for this trait in farmed salmon. Recently, laboratory experiments have shown that the progeny of crosses between ocean-type and stream-type chinook salmon inherit the ocean-type pattern of development, i.e. independent of photoperiod (Clarke and Withler, unpubl. data).

The autumn seawater transfer of salmon is best developed in Japan, where it allowed the harvest of 12,000 t of coho in 1987 (Iwata 1988). Japanese salmon farmers transfer 1-summer-old coho having a minimum size of 120 g to net pens from mid October to early December when seawater temperatures fall below 17-18°C (Iwata and Clarke 1987).

Frantsi and Justason (1988) noted that off-season transfer of yearling Atlantic salmon smolts could be used to increase hatchery efficiency and spread the harvest season in New Brunswick salmon farms. Similar efforts are underway in Norway to test autumn transfers of 0+ Atlantic salmon smolts (T. Hansen, Matre Aquaculture Station, Matredal, Norway, pers. comm.). In southwestern British Columbia, some salmon farmers are experimenting with late autumn transfers as a means of avoiding a noxious diatom bloom which may occur in early autumn.

FRESHWATER NET PENS

Freshwater net pens are being used increasingly as a cheaper alternative to conventional hatcheries with expensive tanks and plumbing. Net pens can reduce the cost of smolt production, particularly for Atlantic salmon, but the grower must accept greater risk of disease outbreaks and less certainty about inventory. In Scotland, more than half of the Atlantic salmon smolts used in salmon farms are now produced in freshwater pens (Aldridge 1988). Two smolt producers in British Columbia are using freshwater net pens to produce large 0+ coho and chinook salmon smolts for autumn transfer to seawater.

REFERENCES

Adams, C. E., and J. E. Thorpe. 1989. Photoperiod and temperature influences on growth in juvenile Atlantic salmon, *Salmo salar*, L. In N. DePauw, E. Jaspers, H. Ackefors and N. Wilkins [ed.] Aquaculture - a biotechnology in progress. 1988. European Aquaculture Society, Bredene, Belgium.

Aldridge, C. H. 1988. Atlantic salmon pen strategies in Scotland. Proc.Aquaculture International Congress, Vancouver, Sept. 6-9, 1988, p. 405-407.

Bailey, J. K., R. L. Saunders, and M. I. Buzeta. 1980. Influence of parental smolt age and sea age on growth and smolting of hatchery-reared Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 37: 1379-1386.

Björnsson, B. T., H. Thorarensen, T. Hirano, T. Ogasawara, and J. B. Kristinsson. 1989. Photoperiod and temperature affects plasma growth hormone levels, growth, condition factor and hypoosmoregulatory ability of juvenile Atlantic salmon (*Salmo salar*) during parr-smolt transformation. Aquaculture 82: 77-92.

Brannon, E., C. Feldmann, and L. Donaldson. 1982. University of Washington zero-age coho salmon smolt production. Aquaculture 28: 195-200.

Clarke, W. C. 1988. Rearing strategies for zero-age coho salmon, *Oncorhynchus kisutch*. Proc. Aquaculture International Congress, Vancouver, Sept. 6-9, 1988, p. 387-390.

Clarke, W. C., and Y. Nagahama. 1977. Effect of premature transfer to seawater on growth and morphology of the pituitary, thyroid, pancreas, and interrenal in juvenile coho salmon (*Oncorhynchus kisutch*). Can. J. Zool. 55: 1620-1630.

Clarke, W. C., and J. E. Shelbourn. 1986. Delayed photoperiod produces more uniform growth and greater seawater adaptability in underyearling coho salmon (*Oncorhynchus kisutch*). Aquaculture 56: 287-299.

Clarke, W. C., and J. E. Shelbourn. 1989. Temperature requirements for production of zero age coho salmon (*Oncorhynchus kisutch*) smolts. In N. DePauw, E. Jaspers, H. Ackefors and N. Wilkins [ed.] Aquaculture - a biotechnology in progress. 1988. European Aquaculture Society, Bredene, Belgium.

Clarke, W. C., J. E. Shelbourn, and J. R. Brett. 1978. Growth and adaptation to sea water in 'underyearling' sockeye (*Oncorhynchus nerka*) and coho (*O. kisutch*) salmon subjected to regimes of constant or changing temperature and day length. Can. J. Zool. 56: 2413-2421.

Clarke, W. C., J. E. Shelbourn, and J. R. Brett. 1981. Effect of artificial photoperiod cycles, temperature and salinity on growth and smolting of underyearling coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*) and sockeye (*O. nerka*) salmon. Aquaculture 22: 105-116.

Clarke, W. C., J. E. Shelbourn, T. Ogasawara, and T. Hirano. 1989. Effect of initial daylength on growth, seawater adaptability and plasma growth hormone levels in underyearling coho, chinook, and chum salmon. Aquaculture 82: 51-62.

Eriksson, L.-O., and H. Lundqvist. 1982. Circannual rhythms and photoperiod regulation of growth and smolting in Baltic salmon (*Salmo salar* L.). Aquaculture 28: 113-121.

Folmar, L. C., and W. W. Dickhoff. 1980. The parr-smolt transformation (smoltification) and seawater adaptation in salmonids. Aquaculture 21: 1-37.

Frantsi, C., and B. Justason. 1988. Different strategies for the transfer of Atlantic salmon smolts to sea water. Bull. Aquacult. Assoc. Can. 88-3: 36-41.

Gjedrem, T., and K. Gunnes. 1978. Comparison of growth rates in Atlantic salmon, pink salmon, Arctic char, sea trout and rainbow trout under Norwegian farming conditions. Aquaculture 13: 135-141.

Harache, Y., G. Boeuf, and P. Lasserre. 1980. Osmotic adaptation of *Oncorhynchus kisutch* Walbaum. III. Survival and growth of juvenile coho salmon transferred to sea water at various times of the year. Aquaculture 19: 253-273.

Healey, M. C. 1983. Coastwide distribution and ocean migration patterns of stream- and ocean-type chinook salmon, *Oncorhynchus tschawytscha*. Can. Field-Natur. 97: 427-433.

Hoar, W. S. 1988. The physiology of smolting salmonids, p. 275-343. In W. S. Hoar and D. J. Randall [ed.] Fish Physiology, Vol. 11B. Academic Press, San Diego.

Isaksson, A. 1985. The production of one-year smolts and prospects of producing zero-smolts of Atlantic salmon in Iceland using geothermal resources. Aquaculture 45: 305-319.

Iwata, M. 1988. Smoltification, seawater adaptability and the growth of coho salmon (*Oncorhynchus kisutch*) in relation to the culture environments in Japan. Proceed. Aquaculture International, Vancouver, p. 391-397.

Iwata, M., and W. C. Clarke. 1987. Culturing coho Japanese-style. Can. Aquacult. 3: 28-31.

Johnsson, J., and W. C. Clarke. 1988. Development of seawater adaptation in juvenile steelhead trout (*Salmo gairdneri*) and domesticated rainbow trout (*Salmo gairdneri*) - effects of size, temperature and photoperiod. Aquaculture 71: 247-263.

Johnston, C. E., and R. L. Saunders. 1981. Parr-smolt transformation of yearling Atlantic salmon (*Salmo salar*) at several rearing temperatures. Can. J. Fish. Aquat. Sci. 38: 1189-1198.

Kittelsen, A., and T. Gjedrem. 1981. Cooling water from a hydro-power plant used in smolt production, p. 510-513. In Proceedings of the World Symposium on Aquaculture in Heated Effluents and Recirculation Systems, Stavanger, 28-30 May 1980. Vol. II. Berlin.

Komourdjian, M. P., R. L. Saunders and J. C. Fenwick. 1976. Evidence for the role of growth hormone as part of a "light-pituitary" axis in growth and smoltification of Atlantic salmon (*Salmo salar*). Can. J. Zool. 54: 544-551.

Kristinsson, J. B., R. L. Saunders, and A. J. Wiggs. 1985. Growth dynamics during the development of bimodal length-frequency distribution in juvenile Atlantic salmon (*Salmo salar* L.). Aquaculture 45: 1-20.

Mahnken, C., E. Prentice, W. Waknitz, G. Monan, C. Sims, and J. Williams. 1982. The application of recent smoltification research to public hatchery release: an assessment of size/time requirements for Columbia River hatchery coho salmon (*Oncorhynchus kisutch*). Aquaculture 28: 251-268.

Mahnken, C. V. W., and F. W. Waknitz. 1979. Factors affecting growth and survival of coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*O. Tshawytscha*) in saltwater net-pens in Puget Sound. Proc. World Maricult. Soc. 10: 280-305.

McCormick, S. D., and R. L. Saunders. 1987. Preparatory physiological adaptations for marine life of salmonids: osmoregulation, growth and metabolism. Am. Fish. Soc. Symp. 1: 211-229.

McCormick, S. D., R. L. Saunders, E. B. Henderson, and P. R. Harmon. 1987. Photoperiod control of parr-smolt transformation in Atlantic salmon (*Salmo salar*): changes in salinity tolerance, gill Na+,K+,-ATPase and plasma thyroid hormones. Can. J. Fish. Aquat. Sci. 42: 529-538.

Nishioka, R. S., H. A. Bern, K. V. Lai, Y. Nagahama, and E. G. Grau. 1982. Changes in the endocrine organs of coho salmon during normal and abnormal smoltification - an electron-microscope study. Aquaculture 28: 21-38.

Novotny, A. J. 1975. Net-pen culture of Pacific salmon in marine waters. Mar. Fish. Rev. 37: 36-47.

Okumoto, N., K. Ikuta, K. Aida, I. Hanyu, and T. Hirano. 1989. Effects of photoperiod on smolting and hormonal secretion in masu salmon (*Oncorhynchus masou*). Aquaculture 82: 63-76.

Peterson, H. 1973. Smolt rearing methods, equipment and techniques used successfully in Sweden. Intern. Atl. Salmon Found. Spec. Publ. Ser. 2: 32-62.

Saunders, R. L. 1986. The thermal biology of Atlantic salmon: influence of temperature on salmon culture with particular reference to constraints imposed by low temperature, p. 77-90. In L. Nyman [ed.] Aquaculture in subarctic areas. Inst. Freshw. Res., Drottningholm Rep. 63.

Saunders, R. L., and E. B. Henderson. 1970. Influence of photoperiod on smolt development and growth of Atlantic salmon (*Salmo salar*). J. Fish. Res. Board Can. 27: 1295-1311.

Saunders, R. L., E. B. Henderson, and P. R. Harmon. 1987. Extended daylength during autumn enhances growth of juvenile Atlantic salmon. Proc. Ann. Meet. Aquacult. Assoc. Can. 1: 32-33.

Saunders, R. L., J. L. Specker, and M. P. Komourdjian. 1989. Effects of photoperiod on growth and smolting in juvenile Atlantic salmon (*Salmo salar*). Aquaculture 82: 103-118.

Saxton, A. M., R. N. Iwamoto, and W. K. Hershberger. 1983. Smoltification in the net-pen culture of accelerated coho salmon, *Oncorhynchus kisutch* Walbaum: prediction of saltwater performance. J. Fish Biol. 22: 363-370.

Thorarensen, H., and W. C. Clarke. 1989. Smoltification induced by a 'skeleton' photoperiod in underyearling coho salmon (*Oncorhynchus kisutch*). Fish. Physiol. Biochem. 6: 11-18.

Thorarensen, H., W. C. Clarke, and A. P. Farrell. 1989. Effect of photoperiod and various intensities of night illumination on growth and seawater adaptability of juvenile coho salmon (*Oncorhynchus kisutch*). Aquaculture 82: 39-49.

Thorpe, J. E. 1977. Bimodal distribution of length of juvenile Atlantic salmon (*Salmo salar* L.) under artificial rearing conditions. J. Fish Biol. 11: 175-184.

Thorpe, J. E., C. E. Adams, M. S. Miles, and D. S. Keay. 1989. Some influences of photoperiod and temperature on opportunity for growth in juvenile Atlantic salmon, *Salmo salar* L. Aquaculture 82: 119-126.

Thorpe, J. E., C. Talbot, and C. Villarreal. 1982. Bimodality of growth and smolting in Atlantic salmon, *Salmo salar* L. Aquaculture 28: 123-132.

Villarreal, C. A., J. E. Thorpe, and M. S. Miles. 1988. Influence of photoperiod on growth changes in juvenile Atlantic salmon, *Salmo salar* L. J. Fish Biol. 33: 15-30.

Wedemeyer, G. A., R. L. Saunders, and W. C. Clarke. 1980. Economical factors affecting smoltification and early marine survival of anadromous salmonids. Mar. Fish. Rev. 42(6): 1-14.

Zaugg, W. S. 1981. Advanced photoperiod and water temperature effects on gill Na+-K+ adenosine triphosphatase activity and migration of juvenile steelhead (*Salmo gairdneri*). Can. J. Fish. Aquat. Sci. 38: 758-764.

PROSPECTS FOR GROWTH ACCELERATION IN SALMONIDS UTILIZING BIOLOGICALLY ACTIVE PROTEINS AND PEPTIDES

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ABSTRACT

Down, N. E. and E. M. Donaldson. 1991. Prospects for growth acceleration in salmonids utilizing biologically active proteins and peptides, p. 141-152. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

The length of the production cycle and size of salmonids at market are both critical to the economics of salmonid production. Recent experimental studies on utilization of recombinant proteins, synthetic peptides and monoclonal antibodies to accelerate growth in salmonids will be reviewed in the context of future application in production systems.

Studies to date indicate that the most effective family of compounds regulating growth in salmonids is the somatotropins. Both natural and recombinant mammalian, avian and piscine somatotropins and their analogs have been shown to significantly accelerate growth in salmonids. Other proteins and peptides believed to be involved in growth regulation have so far proven less effective.

Further research will determine the commercial applicability of these compounds and is expected to focus on: efficacy of somatotropins from different species, use of somatotropin analogs, development of practical means of administration, further investigation of other growth regulators and provision of data to meet regulatory requirements.

RÉSUMÉ

Down, N. E. and E. M. Donaldson. 1991. Prospects for growth acceleration in salmonids utilizing biologically active proteins and peptides, p. 141-152. In R. H. Cook and W. Pennell (ed.) Proceedings of the special session on salmonid aquaculture, World Aquaculture Society, February 16, 1989, Los Angeles, USA. Can. Tech. Rep. Fish. Aquat. Sci. 1831.

La longueur du cycle de production et la taille commerciale des salmonidés sont deux facteurs économiques essentiels de la salmoniculture. On examine les résultats d'études expérimentales récentes sur l'utilisation de protéines recombinantes, de peptides synthétiques et d'anticorps monoclaux en vue de leur application future aux systèmes de production.

Les études réalisées jusqu'ici rélèlent que les substances de croissance de la famille de la somatostatine sont les plus efficaces chez les salmonidés. Il s'avère que la somatostatine, naturelle et recombinante, provenant des mammifères, des oiseaux et des poissons, et ses analogues accélèrent notablement la croissance des salmonidés. Les autres protéines et peptides que l'on croit associés à la régulation de la croissance se sont jusqu'ici révélés moins efficaces.

D'autres études seront effectuées pour déterminer les possibilités d'application commerciale de ce type de substance. On s'attend à ce qu'elles portent sur l'efficacité des somatostatines provenant de diverses espèces, sur l'utilisation d'analogues de la somatostatine, sur la recherche de moyens pratiques d'administrer cette substance, sur l'examen plus approfondi des autres substances de croissance et sur la collecte de données susceptibles de répondre aux exigences de la réglementation.

INTRODUCTION

In commercial culture of salmonids, growth rates are of paramount importance in determining whether an operation will be profitable. Furthermore, the current market for Pacific and Atlantic salmon favors a larger product (2-5 kg) which commands a higher price per unit weight. Any technique which improves growth rate, without jeopardizing quality, will benefit the salmonid culturist either by reducing the length of time required to raise a product of a given size (thereby making rearing facilities available for additional stock) or by allowing the production of a larger product during a fixed production cycle. The growth of fish can be influenced by a myriad of factors. Other than the direct effects of temperature on overall metabolism, most of these factors are, in one way or another, mediated by the endocrine system. Even within the endocrine system, growth is regulated by the actions and interactions of a variety of hormonal factors including peptides, proteins, steroids and thyroid hormones (Donaldson et al. 1979). The major growth regulating endocrine axis is centered on adenohypophyseal production and release of somatotropin (STH), which is a moderately sized protein of approximately 22 kDa. STH release in teleosts appears to be regulated in a fashion analogous to that found in other vertebrates (see Hall et al. 1986 for review). Consequently, the hypothalamus interprets internal and external cues and regulates the release of STH through the interaction of peptide releasing and release inhibiting factors. In mammals, STH can act as a trophic hormone and stimulate the release of polypeptide somatomedins which act at the tissue level to stimulate growth. However, STH can also stimulate some growth effects directly, without somatomedin mediation (Laron et al. 1982).

Antibiotic and steroidal growth promoters have been used in animal husbandry for many years. Their use is currently the subject of controversy between the EEC and North America (Levy 1987; Anon. 1989). The use of larger proteins, such as STH, in animal production was not considered practical due to the high cost and limited supply of material that had to be purified from pituitary glands. The use of peptide and protein growth regulators offers several advantages. The main advantage is the highly specific nature of individual proteins which means that STHs can be used which are devoid of biological activity in human beings. Furthermore, they behave as typical proteins in the mammalian digestive tract where they are largely broken down into short chain peptides and constituent amino acids. In salmonids, STH induced the largest growth response when compared to thyroid hormones and anabolic steroids (Higgs et al. 1977). Recent advances in recombinant DNA technology have made it possible to select genes which control the production of selected proteins and to insert these into the genome of prokaryotes such as yeast or *E. coli*. Using established culture techniques and methods for extraction and reconstitution, virtually limitless quantities of the selected protein can be produced in extremely pure form. Thus, the major blockage to the use of substances such as STH has been removed.

Although there is interest in establishing the potential growth benefits that may be derived from peptides and proteins at all levels of the somatotropic axis, to date the majority of the work and the greatest effects have been obtained with STH supplementation. This paper will review recent and ongoing research on the use of peptide and protein growth promoters to enhance the performance of cultured salmonids.

SOURCES AND FORM OF SOMATOTROPIN

Numerous studies have demonstrated the efficacy of pituitary derived growth hormone in improving the growth rate of salmonids. Purified mammalian (usually bovine or porcine) STH was most commonly tested; however, partially purified piscine STH was also successfully employed (Donaldson et al. 1979; Weatherley and Gill 1987). The use of pituitary derived STH in aquaculture was never considered practical due to the high cost and limited supply of this form of STH (Markert et al. 1977).

Recombinant DNA technology provides a means to produce large quantities of specific proteins, such as STH, for the food producing industries at a cost permitting the practical use of such substances on a commercial scale. If a biologically active protein is to be used by the aquaculture industry, it is imperative that the most appropriate sources and forms of the protein be identified. The growth enhancing potential of recombinant STH was first demonstrated by Gill et al. (1985) who showed that pituitary derived bovine STH and recombinant bovine STH (rbST) were of similar potency when tested in juvenile coho salmon (*Oncorhynchus kisutch*). Recombinant chicken STH (rcST) was of somewhat lower potency. Further studies have demonstrated that both rbST and recombinant porcine STH are equipotent when tested in chinook salmon (*O. tshawytscha*) (Down et al. 1988, unpublished). Weatherley and Gill (1987), after reviewing numerous studies in which teleost growth had been hormonally enhanced, suggested that STH forms of different amino acid composition (such as bovine and porcine) appeared to have different potencies in salmonids. Our studies in which direct potency comparisons have been made, using various forms of STH purified in a similar manner and to the same degree, do not support this thesis. It is likely that the structural differences between various forms of STH from tetrapods are much less than the difference between any particular tetrapod form and endogenous salmon STH. Nicoll et al. (1987) note that the overall degree of homology between coho salmon STH and mammalian STH is approximately 38%, which is one-third to one-half that found among most mammalian STHs. It appears, from our data, that salmonids recognize the various tetrapod forms of STH in a similar manner.

Recombinant chum salmon (*O. keta*) STH (rsST) (Kawauchi et al. 1986) and recombinant rainbow trout (*Salmo gairdneri*) STH (rtST) (Agellon et al. 1988) have been shown to be potent growth enhancers in rainbow trout. In both of these studies, weekly injections of 0.1-0.2 µg STH/g bwt induced a marked growth response. In our laboratory, similar studies were conducted using mammalian or avian STH to treat juvenile coho salmon (Gill et al. 1985; Down et al. 1989). We found a dosage of 0.5-10.0 µg STH/g bwt produces a consistent, dose-dependent growth response. This implies that homologous forms of STH might be more potent growth enhancers in fish as one might predict; however, a direct comparison of similarly purified salmonid and tetrapod somatotropins has not, to our knowledge, been completed. Clarke et al. (1977) reported that purified Tilapia STH was approximately equipotent to pituitary bovine STH when tested in juvenile sockeye salmon (*O. nerka*). Higgs et al. (1978) compared the potency of pituitary bovine STH and a partially purified chinook salmon STH in juvenile coho salmon. The bovine preparation was approximately 10 times more potent than would be expected from differences in purity of the two preparations.

These studies, utilizing recombinant STH, used molecules which were based on the natural DNA sequence of the STH gene in lower species. Consequently, the recombinant STH had the same amino acid composition, amino acid sequence and molecular weight as the native molecule. However, recombinant DNA technology makes it possible to produce protein engineered analogs of the native molecule with amino acid additions, substitutions or deletions. Superactive analogs of the relatively small peptide, GnRH, have been successfully synthesized and their potential for use in aquaculture has been demonstrated (Peter et al. 1985; Van der Kraak et al. 1987). Larger proteins, such as STH, cannot easily be synthesized; however, changes such as amino acid deletions can be accomplished relatively easily in a recombinant molecule. Recently, Down et al. (1989) have provided the first data on the use of such an analog in teleosts. The deletion of seven amino acids (positions 33-39) from the rbST molecule resulted in a 21-kDa protein which was approximately nine times more potent in enhancing weight and length gains of juvenile coho salmon than the native form of the molecule (22 kDa rbST). Analogs such as this may have prolonged clearance rates which would be advantageous to aquaculture applications where handling must be minimized.

EFFECT OF STH DURING DIFFERENT LIFE HISTORY STAGES

Until recently, almost all studies in which STH was employed as a growth enhancer in salmonids utilized salmon or trout at the parr stage in fresh water. Without exception, these studies indicated that STH was a growth limiting factor (see reviews by Donaldson et al. 1979; Weatherley and Gill 1987). It was not clear from these studies whether STH availability was also limiting growth during early fry development, during smolting or during the seawater grow-out phases of the production cycle. Some of these questions are now being answered.

Newly emerged salmonid fry make a transition to exogenous feeding preceded or accompanied by a number of endocrinological events (Specker 1988). It is not clear, however, what role STH plays during this early, rapid growth phase. In one study (Down et al., unpublished), we found that newly emerged chinook salmon (0.5 g) did not respond to exogenous STH treatment (5.0 µg ovine STH/g bwt/week) until they reached approximately 2 g in body weight. At this size, fish which had received five previous treatments began to respond with an accelerated rate of growth. Fish given their first treatment after attaining a body weight of 2 g responded to the first injection and a size difference, relative to the control group, was noted after only 2 wk. A similar situation has been noted for chum salmon immersed in a solution of salmon STH (H. Kawauchi, pers. comm.).

Although the growth effects of STH treatment have apparently not been investigated in smolting salmonids, there is growing evidence that STH may play an integral role in seawater adaptation. Numerous studies on juvenile salmonids have indicated that circulating STH levels increase in response to saltwater transfer or that STH treatment can lower circulating sodium levels and increase initial saltwater survival (Clarke et al. 1977; Sweeting et al. 1985; Miwa and Inui 1985; Sweeting and McKeown 1987; Bolton et al. 1987; Richman et al. 1987; Hasegawa et al. 1987). Possibly, STH therapy during the critical preparatory period prior to saltwater entry may enhance smolting success.

The culture of salmon usually entails a postsmolt saltwater rearing phase during which the greatest increase in mass is accumulated. It was, therefore, of considerable interest to determine if the supplementation of STH levels during this period would produce a substantial growth effect. Down et al. (1988a) tested the effects of rbST on subadult coho salmon during their first 'sea-winter'. Under these conditions, the specific growth rate was more than doubled by rbST when administered by a variety of techniques at two dose levels. We have also completed two as yet unpublished studies which demonstrate the effectiveness of rbST in enhancing growth of subadult chinook salmon during summer. Presumably, as salmon approach sexual maturity, the growth effect of STH will diminish. However, to date we have not identified any period during the normal saltwater production cycle when STH therapy is not a significant growth enhancer.

MODE OF ADMINISTRATION

The majority of studies in which STH has been used to accelerate growth has used parenteral modes of administration. For experimental purposes, these routes are effective and reliable. Down et al. (1988b) described the plasma kinetics for rcST when delivered by injection to juvenile coho salmon. There were only minor differences in the response to intramuscular and intraperitoneal routes of administration. The plasma level of rcST was proportional to the dose, but plasma clearance rates were independent of dose. These data indicated that STH at a dose of 5 µg/g/bwt (which is near the maximally effective dose) had to be delivered every 7-14 d to maintain an effective plasma STH concentration. Further studies (Down et al. 1988c) indicated that this treatment interval could be somewhat increased by implanting cholesterol pellets containing STH or markedly increased through the use of mini-osmotic pumps. The maximum circulating concentration of STH attained by this latter technique was approximately 100-fold lower than the peak concentration attained when a similar dose of rcST was administered by injection; however, the growth response to a single implanted pump was as great or greater than that induced by four biweekly injections (Down et al. 1988a).

The significance of this last observation is two-fold. First, it is now apparent that the large pulses of STH obtained with bolus injection are not necessary to achieve a good growth response. Second, chronic infusion of STH does not lead to receptor down-regulation and loss of growth response. This implies that if a practical method of administration could be achieved, then salmon should continue responding to a chronic treatment for an extended period.

The development of a practical mode of STH administration, i.e. one that could be profitably carried out under commercial conditions, is of paramount importance if recombinant STH is to be used as a growth enhancer. Three general possibilities exist: parenteral administration of an inexpensive slow-release system, administration via the water or administration via the feed.

Although STH is a moderately large protein (approximately 191 amino acids with a MW of 22 kDa), at least two studies have indicated that biologically active STH can pass through gill epithelium. Agellon et al. (1988) achieved a 29% increase in specific growth rate of rainbow trout immersed in a 0.05 or 0.5 mg/L solution of rtST relative to saline immersed control fish. Schulte et al. (1989) required a much higher concentration of rbST analog (100 mg/L) to achieve comparable results using a different immersion protocol. Schulte et al. (1989), however, also noted that the effect of immersion was minimal when compared to the results of regular injections. Furthermore, these authors found their immersion protocol could be inhibitory to growth, possibly due to excessive stress. More work is required to determine if a practical immersion protocol can be developed.

The dietary application of STH has often been considered impractical due to gastric degradation. However, Degani and Gallagher (1985) found that eels (*Anguilla rostrata*) did respond to a diet containing bovine STH. We have made a similar observation in chinook salmon fed a diet supplemented with bovine STH. The results were somewhat ambiguous, but we did observe a significant improvement in growth with a pelleted diet containing 50 mg STH/kg feed (Down et al., unpublished). McLean et al. (1988) incubated juvenile coho salmon with rbST by both oral and rectal routes. The resulting plasma levels of rbST were determined by homologous RIA. These data indicated that immunologically active STH could pass gut epithelium, but the oral route resulted in a lower circulating level than the rectal route. These data imply that if STH presented in the diet can be protected from gastric digestion, then an improved growth response can be predicted.

ENVIRONMENTAL FACTORS

As noted in the section, Effect of STH During Different Life History Stages, the majority of studies in which STH has been employed as a growth stimulant have been undertaken in summer. It was not known if STH supplementation would affect growth when the growth rate was low due to environmental constraints such as temperature and photoperiod. Down et al. (1988a) tested the effect of rbST delivered to subadult coho salmon acclimatized to seawater and found that the growth rate could be more than doubled under winter temperature and photoperiod conditions. The mean water temperature in this experiment was relatively cold (7.4°C), although not atypical for southern British Columbia (Canada). The growth rates achieved with STH stimulation were not exceptional, but were considerably greater than the growth rate of control fish. We suggested that the greatest relative gains in growth rate might be achieved when the intrinsic growth rate is low.

This supposition is supported by the data presented in Fig. 1. The results of two experiments are presented here, both conducted on juvenile coho salmon from the Capilano Hatchery (North Vancouver, B.C., Canada) stock. Both

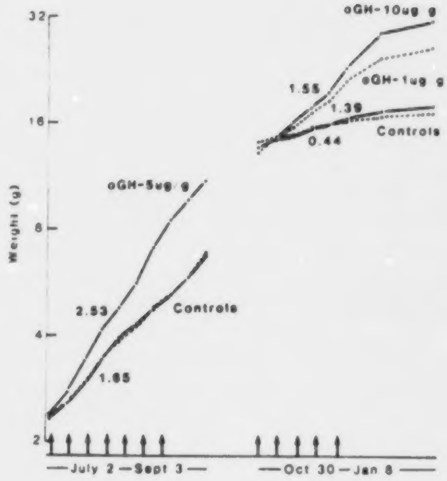

Fig. 1. Growth curves for juvenile coho salmon reared in fresh water at 10°C under either summer or winter photoperiod. Control fish were either untreated or sham-injected. Treated fish received weekly intraperitoneal injections (arrows) of ovine somatotropin (oGH) at the dose levels indicated. Specific growth rates for the treatment period are indicated for each curve. Experimental conditions were the same for both trials with the exceptions of the starting size of the salmon used and the photoperiod (which was controlled by photocell to match the ambient photoperiod).

growth trials were conducted in well water at 10°C and each experimental group was duplicated. The same size aquaria, approximately the same densities of fish, the same diets and the same feeding regimes were used in both experiments. Additionally, the same batch of ovine STH (NIADDK-oGH-13) was used as the test substance in both trials. One trial used salmon of 2.3 g mean starting weight and was conducted under ambient summer photoperiod while the other trial used fish which had completed their first summer's growth and had achieved a mean starting weight of 14.2 g. This trial was conducted under the ambient photoperiod for October through January. In both trials, STH significantly improved the specific growth rate. The control fish under winter conditions grew at a rate more than three-fold less than control fish under summer conditions. Since experimental conditions were nearly identical, including temperature, this difference can be attributed to life history stage (the specific growth rate of fish generally decreases with increasing absolute size), to photoperiod (circannual rhythm) or to some combination of both. Although the growth rates achieved with STH under winter photoperiod were not as great as those observed in summer, the relative improvement in growth rate (as compared to control growth rates) was much better in the winter period.

The results of the above mentioned studies on coho salmon may not, however, be universally applicable to salmonids, and the effect of temperature on growth cannot be dismissed. Clarke et al. (unpubl. data) have tested the growth effects of rbST on juvenile Atlantic salmon (*S. salar*) at 6, 10, 14 and 18°C. Unexpectedly, STH therapy was relatively ineffective at 6 and 10°C. Further, there was no clear difference in the effect at 14 and 18°C.

The most appropriate seasons or life history stages at which to treat cultured salmonids with STH to gain maximal benefits will probably have to be determined for each species and for environmental conditions of the geographic region of concern. For example, growth improvements possible under the relatively mild winter conditions on the Pacific coast of Canada may not be possible on the harsher Atlantic coast. It is apparent, however, that opportunities for maximizing the benefits of STH or related therapies by choosing the most appropriate treatment schedules do exist.

OTHER BIOLOGICALLY ACTIVE PEPTIDES AND PROTEINS

While STH is the most studied and most effective biologically active peptide or protein used to date for growth promotion in fish, there is an axis of hormones which works in symphony with STH to regulate growth. The potential for using these other substances as growth enhancers is of interest for several reasons. In studies on the control of fish reproduction, it has been shown that gonadotropin releasing hormone with or without a dopamine antagonist can be used to regulate the production and release of gonadotropin from the pituitary gland, thus regulating gonadal final maturation, ovulation and spermiation (Donaldson and Hunter 1983; Van der Kraak et al. 1986; Peter 1988). A similar system using an STH releasing factor may enable the regulation of endogenous STH production and release in teleosts. Releasing factors are generally smaller peptides which are easily synthesized, may be easier to deliver in slow release preparations and from which superactive analogs containing D amino acids can be derived.

The STH releasing factor of teleosts has not been isolated and characterized to date and its potential as a growth promoter is largely unknown. Pan et al. (1985) detected the presence of human growth hormone releasing factor (hGRF) immunoreactivity in the cod (*Gadus morhua*) brain and pituitary and Peter et al. (1984) measured increased STH secretion in goldfish (*Carassius auratus*) treated with hGRF. Chang et al. (1985) demonstrated that catecholamines could influence STH secretion, but it was not clear if or how these actions were being mediated by hypothalamic factors. A preliminary study by Parker, Sherwood, Luo and McKeown (unpublished) found that immunoreactive salmon GRF, partially purified by HPLC, had STH releasing activity in an *in vitro* rainbow trout pituitary cell culture assay. In the goldfish, gonadotropin releasing hormone can act as an STH releasing factor (Marchant et al. 1989), but this has apparently not been demonstrated for salmonids. Work on isolating and testing the effects of salmonid GRF continues.

In contrast to the paucity of information on teleost STH releasing factors, there is significant evidence that hypothalamic release-inhibiting factors operate in a manner analogous to those described for mammals. Immunocytochemical studies have revealed the presence of somatostatin in the brain and pituitary of numerous teleost species (Dubois et al. 1979; Olivereau et al. 1984; Batten et al. 1985). Further, somatostatin has been shown to inhibit the release of teleost somatotropin in both *in vitro* (Fryer et al. 1979; Wingham and Batten 1984; Batten and Wingham 1984; Marchant et al. 1987) and *in vivo* (Cook and Peter 1984; Sweeting and McKeown 1986) studies. As in mammals, several forms of somatostatin are present in fish, but the structure of somatostatin-14 is identical in all species thus far studied (reviewed by Plisetskaya et al. 1986). Thus, the potential exists for manipulating the neuroendocrinological control system in salmonids, with available mammalian preparations, to enhance the synthesis and release of endogenous somatotropin, which should in turn improve growth.

Immunoneutralization of somatostatin is an experimental technique which has been used successfully to improve the production performance of several mammalian species (reviewed by Spencer 1986) presumably by interfering with somatostatin's inhibitory effect on the somatotrops. Given the apparent homology of somatostatin function between mammals and fishes, the potential exists to use this technique to improve growth and feed efficiency in cultured salmon. This concept is supported by the data of Plisetskaya et al. (1986) who have shown that somatostatin decreases circulating insulin and causes depletion of liver glycogen in coho salmon while passive immunization with antisomatostatin has the opposite effect. The use of somatostatin immunoneutralization as a means of causing the elevated release of endogenous STH in salmon is currently being investigated in our laboratory.

Somatomedins are polypeptide hormones, produced by the liver and peripheral tissues, which mediate some of the growth effects of STH. There are apparently no published accounts in which somatomedins have been tested for growth promoting properties in teleosts. The presence of a substance analogous to human somatomedin has been identified in Atlantic salmon (Lindahl et al. 1985). In that study, somatomedin levels were highest during smolting which is consistent with the elevated STH levels noted by others (see above) during this period. Whether or not somatomedin therapy will stimulate growth in salmonids is still speculative. Mammalian data indicate that somatomedins may act in a paracrine or autocrine fashion rather than being released into the general circulation (Underwood et al. 1986; Schlechter et al. 1986). Furthermore, in some tissues there are direct growth effects of STH that are not mediated through somatomedin (Laron 1982; Schoenle et al. 1985; Zezulak and Green 1986). It is likely, therefore, that the use of somatomedins may not be as effective in inducing rapid growth as is STH. The basic endocrinology of this substance must be established in teleosts before it can be properly assessed as a therapeutic agent.

CONCLUSIONS

There is much to learn about the endocrinology of the STH axis in salmonids and answers to some very basic questions may make the possibility of practical benefits apparent. STH is clearly limiting to growth at most life history stages and may greatly improve the growth of cultured salmon under a variety of conditions.

The major obstacle is a practical means of administration. Once this has been accomplished, production scale trials will enable us to assess the true commercial benefits from using this form of growth enhancement.

REFERENCES

Agellon, L. B., C. J. Emery, J. M. Jones, S. L. Davies, A. D. Dingle, and T. T. Chen. 1988. Promotion of rapid growth of rainbow trout (*Salmo gairdneri*) by a recombinant fish growth hormone. Can. J. Fish. Aquat. Sci. 45: 146-151.

Anonymous. 1989. Brie and hormones. The Economist, January 7, p. 21-22.

Batten, T. F. C., and T. Wigham. 1984. Effects of TRH and somatostatin on releases of prolactin and growth hormone in vitro by the pituitary of *Poecilia latipinna*. II. Electron-microscopic morphometry using automatic image analysis. Cell Tissue Res. 237: 595-603.

Batten, T. F. C., D. J. Groves, J. N. Ball, M. L. Cambre, W. A. Verdonck, F. Ollevier, and F. Vandesande. 1985. Immunocytochemical investigation of forebrain control by somatostatin of the pituitary in the teleost *Poecilia latipinna*. Cell Tissue Res. 242: 115-125.

Bolton, J. P., N. L. Collie, H. Kawauchi, and T. Hirano. 1987. Osmoregulatory actions of growth hormone in rainbow trout (*Salmo gairdneri*). J. Endocrinol. 112: 63-68.

Chang, J. P., T. A. Marchant, A. F. Cook, C. S. Nahorniak, and R. E. Peter. 1985. Influences of catecholamines on growth hormone release in female goldfish, *Carassius auratus*. Neuroendocrinology 40: 463-470.

Clarke, W. C., S. W. Farmer, and K. M. Hartwell. 1977. Effect of teleost pituitary growth hormone on growth of *Tilapia mossambica* and on growth and seawater adaptation of sockeye salmon (*Oncorhynchus nerka*). Gen. Comp. Endocrinol. 33: 174-178.

Cook, A. F., and R. E. Peter. 1984. The effects of somatostatin on serum growth hormone levels in the goldfish, *Carassius auratus*. Gen. Comp. Endocrinol. 54: 109-113.

Degani, G., and M. L. Gallagher. 1985. Effects of dietary 17-methyltestosterone and bovine growth hormone on growth and food conversion of slow- and normally-growing American elvers (*Anguilla rostrata*). Can. J. Fish. Aquat. Sci. 42: 185-189.

Donaldson, E. M., U. H. M. Fagerlund, D. A. Higgs, and J. R. McBride. 1979. Hormonal enhancement of growth in fish, p. 455-597. In W. S. Hoar, D. J. Randall and J. R. Brett (ed.) Fish physiology, Vol. III. Academic Press, New York, NY, USA.

Donaldson, E. M., and G. A. Hunter. 1983. Induced final maturation, ovulation and spermiation in cultured fish, p. 351-403. In W. S. Hoar, D. J. Randall, and E. M. Donaldson (ed.) Fish physiology, Vol. IXB. Academic Press, New York, NY, USA.

Down, N. E., E. M. Donaldson, H. M. Dye, K. Langley, and L. M. Souza. 1988a. Recombinant bovine somatotropin more than doubles the growth rate of coho salmon (*Oncorhynchus kisutch*) acclimated to seawater and ambient winter conditions. Aquaculture 68: 141-155.

Down, N. E., E. M. Donaldson, H. M. Dye, K. Langley, and L. M. Souza. 1988b. Plasma kinetics of injected recombinant chicken somatotropin in juvenile coho salmon (*Oncorhynchus kisutch*) using a homologous radioimmunoassay. Fish. Physiol. Biochem. 5: 49-57.

Down, N. E., H. M. Dye, E. M. Donaldson, and L. M. Souza. 1988c. Plasma kinetics and growth responses to recombinant somatotropin when administered by a variety of techniques to coho salmon. 1st International Symposium on Fish Endocrinology, June 12-17, 1988, Univ. Alberta, Edmonton, Alberta, Canada. Abstr. P8, p. 33.

Down, N. E., E. M. Donaldson, H. M. Dye, T. C. Boone, K. E. Langley, and L. M. Souza. 1989. A potent analog of recombinant bovine somatotropin accelerates growth in juvenile coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 46: 178-183.

Dubois, M. P., R. Billard, B. Breton, and R. E. Peter. 1979. Comparative distribution of somatostatin, LH-RH, neuropysin, and -endorphin in the rainbow trout: an immunocytological study. Gen. Comp. Endocrinol. 37: 220-232.

Fryer, J. N., R. S. Nishioka, and H. A. Bern. 1979. Somatostatin inhibition of teleost growth hormone secretion. Gen. Comp. Endocrinol. 39: 244-246.

Gill, J. A., J. P. Sumpter, E. M. Donaldson, H. M. Dye, L. M. Souza, T. Berg, J. Wypych, and K. Langley. 1985. Recombinant chicken and bovine growth hormones accelerate growth in aquacultured juvenile Pacific salmon *Oncorhynchus kisutch*. Bio/Technology 3: 643-646.

Hall, T. R., S. Harvey, and C. G. Scanes. 1986. Review. Control of growth hormone secretion in the vertebrates: a comparative survey. Comp. Biochem. Physiol. 84A: 231-253.

Hasegawa, S., T. Hirano, T. Ogasawara, M. Iwata, T. Akiyama, and S. Arai. 1987. Osmoregulatory ability of chum salmon, *Oncorhynchus keta*, reared in fresh water for prolonged periods. Fish Physiol. Biochem. 4: 101-110.

Higgs, D. A., E. M. Donaldson, J. R. McBride, and H. M. Dye. 1978. Evaluation of the potential for using a chinook salmon (*Oncorhynchus tshawytscha*) pituitary extract versus bovine growth hormone to enhance the growth of coho salmon (*Oncorhynchus kisutch*). Can. J. Zool. 56: 1226-1231.

Higgs, D. A., U. H. M. Fagerlund, J. R. McBride, H. M. Dye, and E. M. Donaldson. 1977. Influence of combinations of bovine growth hormone, 17-methyltestosterone, and L-thyroxine on growth of yearling coho salmon (*Oncorhynchus kisutch*). Can. J. Zool. 55: 1048-1056.

Kawauchi, H., S. Moriyama, A. Yasuda, K. Yamaguchi, K. Shirahata, J. Kubota, and T. Hirano. 1986. Isolation and characterization of chum salmon growth hormone. Arch. Biochem. Biophys. 244: 542-552.

Laron, Z. 1982. Somatomedin, insulin, growth hormone and growth: a review. Israel J. Med. Sci. 18: 823-829.

Levy, S. B. 1987. Antibiotic use for growth promotion in animals: ecologic and public health consequences. J. Food Protect. 50: 616-620.

Lindahl, K. I., V. Sara, G. Fridberg, and T. Nishimiya. 1985. The presence of somatomedin in the Baltic salmon, *Salmo salar*, with special reference to smoltification. Aquaculture 45: 177-183.

McLean, E., N. E. Down, H. M. Dye, L. M. Souza, and E. M. Donaldson. 1988. Absorption of rbGH by the gastrointestinal tract of coho salmon smolts (*Oncorhynchus kisutch*, Walbaum, 1792): comparison between oral and rectal routes of administration. 1st International Symposium on Fish Endocrinology, June 12-17, 1988, Univ. Alberta, Edmonton, Alberta, Canada. Abstr. P10, p. 34.

Marchant, T. A., R. A. Fraser, P. C. Andrews, and R. E. Peter. 1987. The influence of mammalian and teleost somatostatins on the secretion of growth hormone from goldfish (*Carassius auratus* L.) pituitary fragments *in vitro*. Regulatory Peptides 17: 41-52.

Marchant, T. A., J. P. Chang, C. S. Nahorniak, and R. E. Peter. 1989. Evidence that gonadotropin-releasing hormone also functions as a growth hormone releasing factor in goldfish. Endocrinology 124: 2509-2518.

Markert, J. R., D. A. Higgs, H. M. Dye, and D. W. MacQuarrie. 1977. Influence of bovine growth hormone on growth rate, appetite and food conversion of yearling coho salmon (*Oncorhynchus kisutch*) fed two diets of different composition. Can. J. Zool. 55: 74-83.

Miwa, S., and Y. Inui. 1985. Effects of L-thyroxine and ovine growth hormone on smoltification of amago salmon (*Oncorhynchus rhodurus*). Gen. Comp. Endocrinol. 58: 436-442.

Nicoll, C. S., S. S. Steiny, D. S. King, R. S. Nishioka, G. L. Mayer, N. L. Eberhardt, J. D. Baxter, M. K. Yamanaka, J. A. Miller, J. J. Seilhamer, J. W. Schilling, and L. K. Johnson. 1987. The primary structure of coho salmon growth hormone and its cDNA. Gen. Comp. Endocrinol. 68: 387-399.

Olivereau, M., F. Ollevier, F. Vandesande, and J. Olivereau. 1984. Somatostatin in the brain and the pituitary of some teleosts. Immunocytochemical identification and the effect of starvation. Cell Tissue Res. 238: 289-296.

Pan, J. X., R. M. Lechan, H. D. Lin, J. Sohn, S. Reichlin, and I. M. D. Jackson. 1985. Multiple forms of human pancreatic growth hormone releasing factor-like immunoreactivity in teleost brain and pituitary. Endocrinology 116: 1663-1665.

Peter, R. E., H. R. Lin, and G. Van der Kraak. 1988. Induced spawning in Chinese carps, p. 543-547. In Proc. Aquaculture International Congress and Exposition, Vancouver Trade & Convention Centre, Vancouver, B.C. Aquaculture International Congress, British Columbia Pavilion Corp., Vancouver, British Columbia, Canada, Sept. 6-9, 1988.

Peter, R. E., C. S. Nahorniak, M. Sokolowska, J. P. Chang, J. E. Rivier, W. W. Vale, J. A. King, and R. P. Millar. 1985. Structure-activity relationships of mammalian, chicken, and salmon gonadotropin releasing hormones *in vivo* in goldfish. Gen. Comp. Endocrinol. 58: 231-242.

Peter, R. E., C. S. Nahorniak, W. W. Vale, and J. E. Rivier. 1984. Rapid communication. Human pancreatic growth hormone-releasing factor (hpGRF) stimulates growth hormone release in goldfish. J. Exper. Zool. 231: 161-163.

Plisetskaya, E. M., H. G. Pollock, J. B. Rouse, J. W. Hamilton, J. R. Kimmel, P. C. Andrews, and A. Gorbman. 1986. Characterization of coho salmon (*Oncorhynchus kisutch*) islet somatostatins. Gen. Comp. Endocrinol. 63: 252-263.

Richman, N. H., III, R. S. Nishioka, G. Young, and H. A. Bern. 1987. Effects of cortisol and growth hormone replacement on osmoregulation in hypophysectomized coho salmon (*Oncorhynchus kisutch*). Gen. Comp. Endocrinol. 67: 194-201.

Schlecter, N. L., S. M. Russell, E. M. Spencer, and C. S. Nicoll. 1986. Evidence suggesting that the direct growth-promoting effect of growth hormone on cartilage *in vivo* is mediated by local production of somatomedin. Proc. Nat'l. Acad. Sci. USA 83: 7932-7934.

Schoenle, E., J. Zapf, C. Hauri, T. Steiner, and E. R. Froesch. 1985. Comparison of *in vivo* effects of insulin-like growth factors I and II and of growth hormone in hypophysectomized rats. Acta Endocrinol. 108: 167-174.

Schulte, P. M., N. E. Down, E. M. Donaldson, and L. M. Souza. 1989. Experimental administration of growth hormone to juvenile rainbow trout (*Salmo gairdneri*) by injection or by immersion. Aquaculture 76: 145-156.

Specker, J. L. 1988. Preadaptive role of thyroid hormones in larval and juvenile salmon: growth, the gut and evolutionary considerations. Amer. Zool. 28: 337-349.

Spencer, G. S. G. 1986. Hormonal manipulation of animal production by immunoneutralization, p. 279-291. In P. J. Buttery, D. B. Lindsay and N. B. Haynes (ed.) Control and manipulation of animal growth. Butterworths, Toronto, Canada.

Sweeting, R. M., and B. A. McKeown. 1986. Somatostatin reduces plasma growth hormone levels during seawater adaptation in coho salmon, *Oncorhynchus kisutch*. Can. J. Zool. 64: 2062-2063.

Sweeting, R. M., and B. A. McKeown. 1987. Growth hormone and seawater adaptation in coho salmon, *Oncorhynchus kisutch*. Comp. Biochem. Physiol. 88A: 147-151.

Sweeting, R. M., G. R. Wagner, and B. A. McKeown. 1985. Changes in plasma glucose, amino acid nitrogen and growth hormone during smoltification and seawater adaptation in coho salmon, *Oncorhynchus kisutch*. Aquaculture 45: 185-197.

Underwood, L. E., A. J. D'Ercole, D. R. Clemmons, and J. J. Van Wyk. 1986. Paracrine functions of somatomedins. Clin. Endocrinol. Metab. 15: 59-77.

Van Der Kraak, G., E. M. Donaldson, and J. P. Chang. 1986. Dopamine involvement in the regulation of gonadotropin secretion in coho salmon. Can. J. Zool. 64: 1245-1248.

Van Der Kraak, G., E. M. Donaldson, H. M. Dye, G. A. Hunter, J. E. Rivier, and W. W. Vale. 1987. Effect of mammalian and salmon gonadotropin-releasing hormones and analogues on plasma gonadotropin levels and ovulation in coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 44: 1930-1935.

Weatherley, A. H., and H. S. Gill. 1987. The biology of fish growth. Academic Press, Toronto, Canada.

Wigham, T., and T. F. C. Batten. 1984. *In vitro* effects of thyrotropin-releasing hormone and somatostatin on prolactin and growth hormone release by the pituitary of *Poecillia latipinna*. I. An electrophoretic study. Gen. Comp. Endocrinol. 55: 444-449.

Zezulak, K. M., and H. Green. 1986. The generation of insulin-like growth factor-1-sensitive cells by growth hormone action. Science 233: 551-553.

THE MARKET FOR FRESH/FARMED SALMON PRODUCTS: SOME RESULTS FOR THE UNITED STATES AND JAPAN

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INTRODUCTION

Over the past few years, interest in analysis of world salmon markets has continued to increase as the production of aquacultured salmon reaches new heights each year. World-wide pen-raised production in 1977 was only about 2400 metric tons (MT). By 1987, production had increased more than 25 times to about 68,000 MT (approximately 85% of 1986 production was of Atlantic salmon). Projections indicate that farmed salmon could exceed 190,000 MT by 1990 and 350,000 MT by the year 2000 (Egan and Lietz 1988). For the last 5 yr, total ocean-caught salmon ranged between 600,000 and 800,000 MT. It is expected that the ocean catch will not expand rapidly and that, by the end of this century, farmed salmon will account for over 30% of total supply. Farmed salmon will represent an increasingly greater share of the fresh/frozen salmon market.

Clearly, with such rapid growth in farmed salmon production, there is a need to investigate the market. In order to make judicious decisions, producers must obtain the best information to be successful in this increasingly competitive arena. This paper will present some recent results of work done on the U.S. and Japanese salmon markets. This work is not comprehensive and much more needs to be learned.

THE U.S. MARKET FOR SALMON

From the salmon aquaculturist perspective, the fresh, frozen and smoked markets are primary targets. The canned market is not economically feasible for aquaculturists. Imports of whole fresh salmon from 1984-87 are found in Table 1. These figures represent about 13-19% of world-wide farmed salmon production. Over 50% of the fresh imports come into the northeastern U.S. and most likely is consumed in this region. Notably, over 70% of the fresh frozen salmon from Norway, Scotland and Ireland is imported by cities from the East, north of Washington, D.C. (U.S.D.C. 1984-1987). As these imports increase, what are the possible price implications? How can farmed salmon producers expand the U.S. market to keep up with production?

Recently, there have been a few studies which address these questions. Lin and Hermann (1988) studied the U.S. demand for Norwegian Atlantic salmon as a function of the real price of Atlantic salmon, the real ex-vessel price of chinook salmon, real per capita income, lagged consumption. Their data consisted of 68 monthly observations ending February 1988. Using a Box-Cox flexible functional form, they estimated the short- and long-run demand elasticities for Atlantic salmon price, ex-vessel chinook price and income. The mean value of short-run elasticities were -1.44, 0.11 and 3.61, respectively. The mean value of long-run elasticities were -2.05, 0.16 and 5.16, respectively. Other work by Lin et al. (1988) used a two-stage least squares estimate of a double long-functional form for U.S. demand for Norwegian Atlantic salmon, E.C. demand for Norwegian Atlantic salmon and Norwegian supply. This work indicated that the U.S. elasticities for Norwegian Atlantic salmon prices, chinook prices and income were -3.35, 0.36 and 5.01, respectively. The estimates were based on monthly data from January 1983 through March 1987. The two studies both indicate that the U.S. demand for Norwegian Atlantic salmon is price and income elastic. However, the cross-price effect between ex-vessel chinook price and Norwegian Atlantic salmon demand was minimal. Notably, many consider chinook a direct substitute and, therefore, one might expect a stronger relationship than was found. The relationship was weak, partly because most of the price variation for ex-vessel chinook occurs when the imports of Norwegian salmon are low. In addition, the U.S. Norwegian Atlantic salmon prices are based on Norwegian data and were largely determined in the northeastern U.S., while the ex-vessel chinook prices used were determined in Seattle.

Lin et al. (1988) used the econometric estimates from the second study, along with time series estimates of exogenous variables, to forecast future prices for Norwegian Atlantic salmon. These conditional results indicate that by 1991 the price of fresh Norwegian Atlantic salmon will probably decline 20-25% below 1987 levels.

U.S. BUYERS' PERCEPTION OF SALMON

The Lin et al. (1988) work is limited to aggregate price and income effects. In order to develop an understanding of firm level perceptions of salmon products and to attempt to

Table 1. Fresh salmon imports (whole) (metric tons).

	1984	1985	1986	1987
Norway	3888.0	6257.2	8852.8	7640.0
United Kingdom	103.9	393.6	366.7	564.8
Iceland	<.04	14.9	20.7	46.6
Canada	2522.5	1461.5	2477.8	3854.6
Chile	32.3	144.6	679.4	833.8
New Zealand	9.6	97.9	160.8	133.3
Other	271.6	367.8	358.2	515.7
TOTAL	6825.1	8737.4	12918.3	13588.8

estimate firm level demand, a highly disaggregated survey approach was used in recent studies by Anderson (1988) and Anderson and Brooks (1986).

The approach taken in their research was to explore the question of substitutability in detail using conjoint measurement (Green and Wind 1975) and self-explicated utility measurement. Both approaches attempt to determine product preference based on the various attributes of the product. Attributes considered were species, region of origin, method of catch, fresh or frozen, quality, color, seasonality, price and container size.

Conjoint measurement techniques use information on composite product preference and statistical techniques to decompose the preference rating based on the relative importance of the attributes. Self-explicated utility measurement uses the buyer's relative preference for individual attribute level evaluations (coho, chinook, Atlantic) and overall attribute importance (species, in general) to develop a total preference rating.

Data from the conjoint analysis were collected from a random sample of 253 restaurants (173 were fast food, bars, out-of-business or Chinese or Mexican, leaving a sample of possible salmon users of 80), 32 fish stores and 17 grocery/supermarkets in New England (Anderson and Brooks 1986). Completed surveys were obtained from 65 restaurants, 20 fish stores and 10 grocery stores. This sample was augmented in January 1988 with 13 additional interviews of buyers for retail outlets (11 supermarkets, 2 fish stores), 19 retail restaurant buyers and distributors in the Seattle vicinity and 16 interviews of Japanese traders in Vancouver and Seattle. The preference information collected in the augmented sample was analyzed using self-explicated utility measurement (see Anderson 1988).

The relative importance of various attributes and attribute levels was determined using the approaches discussed above and in greater detail in Anderson 1988. This research indicated that salmon could be rated by the relative preferences of various buyers. For example, a seasonal, fresh, troll-caught Alaskan chinook, 9-12 lb, dressed, head-off, deep red, high quality (more than 9 d of shelf life) in 50-lb containers at $4.00/lb salmon could be explicitly compared to one characterized by year-round, fresh, Norwegian, pen-raised, Atlantic salmon, high quality, dressed, head-on, medium red, in 50-lb containers selling for $5.00/lb.

Relative importance of overall attributes

To determine the relative importance of product attributes, buyers were first asked to assess the relative importance of overall attributes in their purchase decision. The results are presented for eight market segments in Fig. 1 and 2: Northeast expensive restaurants (seafood and non-seafood), restaurants with an average entree price of greater than $11.00 (seafood and non-seafood), Northeast moderately priced restaurants - restaurants with an average entree price less than or equal to $11.00; Northeast seafood markets; Northeast supermarkets; Pacific Northwest retail buyers

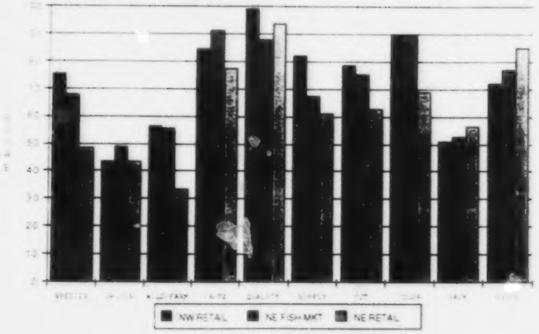

Fig. 1. Overall attribute ratings (retail).

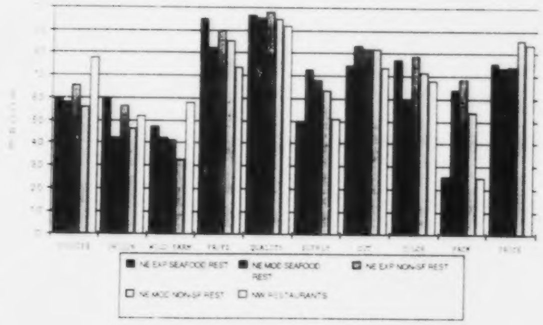

Fig. 2. Overall attribute ratings (restaurants).

(86% of the sample were buyers for supermarkets and 14% were buyers for seafood markets); all Pacific Northwest restaurant buyers.

Quality was the most important factor, followed in general by whether the product was fresh or frozen, price and product form. The importance of other attributes tends to vary depending on market segment. This variation in attribute importance can be more clearly seen in the graphical presentations.

Figure 1 highlights differences between buyers in the retail sector. Note the relative unimportance of species, region of origin and method of catch and the importance of quality and price to buyers for Northeast retail outlets (supermarkets). Also, note that buyers for specialty fish markets have a preference rating very similar to retail buyers in the Pacific Northwest, with the exception of the greater importance which they place on supply factors. Figure 2 contrasts buyers for restaurants. Expensive restaurants in the Northeast place more importance on quality, fresh versus frozen, color and region of origin than the restaurants sampled in the Northwest or moderately priced restaurants in the Northeast. Species and method of catch are relatively less important as one moves from Northwest restaurants to expensive Northeast restaurants to moderately priced Northeast restaurants. The relationship is the opposite for supply and product size and cut.

While this ordering is valuable, it cannot be used by itself to determine the degree to which the levels of the attributes ($4.00/lb or $6.00/lb? high quality versus medium quality? chinook, Atlantic or coho? whole head-on, whole head-off, steaks or fillets?) will be relatively preferred in the buyers' evaluation of the product.

Importance of individual attributes

The following was derived from updated econometric work used to determine attribute coefficients in the conjoint measurement procedure for Northeast restaurant buyers and directly from buyer ratings for the Northeast retail buyers and Northwest buyers (Anderson and Brooks 1986).

Species

Figure 3 compares the relative degree of preference of species for four market segments (10 is the most preferred; 5 is neutral; and 1 is least preferred).

Retail: Northwest retail buyers favor chinook (king), coho and sockeye. They are either neutral or do not know about Atlantics and chums. The majority of Northeast retailers either do not know or are indifferent about salmon species. However, Atlantics followed by chinook are viewed favorably by most.

Restaurants: In the Northwest, buyers prefer coho, chinook and sockeye and there is a notably negative perception of Atlantic salmon.

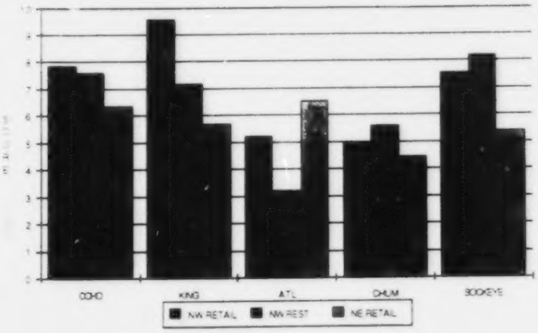

Fig. 3. Preference ratings for salmon species.

In the Northeast, expensive seafood restaurants indicate a significant relative preference for chinook, Atlantic and coho (results derived from econometric equations found in Anderson (1988); not shown graphically).

For other restaurant groups, Atlantic, chinook and coho tend to be relatively preferred. However, in most cases they cannot be shown to be statistically different from each other within this market.

Region of origin

Retail: Retail buyers in the Northwest have relatively strong preference for local (U.S. West Coast) or Alaskan salmon products. Canadian salmon is also positively perceived. They tended to be negative or neutral about the other sources of supply (see Fig. 4).

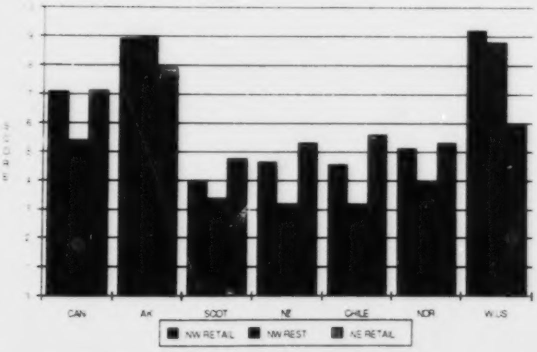

Fig. 4. Preference ratings for regions of orgin.

The buyers in the Northeast also preferred salmon from Alaska, followed by Canada and the U.S. West Coast, all else being equal. They were generally neutral or did not know about the other countries, but Chile, Norway and New Zealand were rated slightly on the positive side of neutrality.

Restaurants: Northwest restaurants have a strong preference for Alaskan or local (U.S. West Coast) salmon. Canadian salmon was rated only slightly above neutral. The countries which supply farmed salmon, Scotland, New Zealand, Chile and Norway, are all perceived negatively.

The relative rating of country of origin is derived from the econometrically estimated equation in Anderson (1988). Expensive restaurants tend to relatively favor the Norwegian product, followed by the U.S. or Chile, then Canada. However, in most cases, the coefficients are only marginally significant or insignificant. For inexpensive seafood restaurants, Chilean and U.S. salmon are significantly preferred, followed by New Zealand and Norway (marginally significant). Among moderate non-seafood restaurants, no country is significantly different.

Ocean-caught versus farmed salmon

Retail: As shown in Fig. 5, Northwest retailers strongly prefer troll-caught salmon but also rated farmed salmon positively. Seine and gillnet salmon were viewed neutrally.

Most Northeast retailers were neutral or did not know about method of catch. However, farmed salmon were rated on the positive side of neutral.

Restaurants: Northwest restaurants prefer troll-caught followed by gillnet and seine net. They are neural about farmed fish.

Northeast expensive, non-seafood restaurants prefer ocean-caught fish, all else being equal; expensive seafood restaurants consider them insignificantly different. Inexpensive seafood restaurants appear to relatively prefer farmed fish. Moderate non-seafood restaurants are neutral about method of catch.

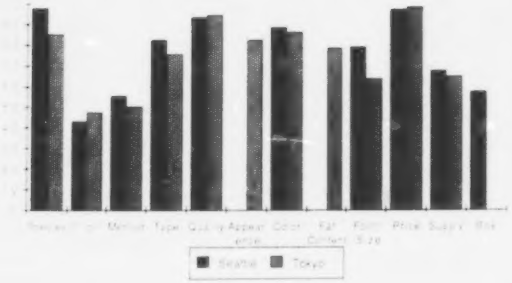

Fig. 5. Overall attribute ratings (Japanese traders).

Fresh/frozen and quality (quality is measured by shelf life and external appearance)

Retail: The order of preference for Northwest retailers is high quality fresh, high quality frozen, medium quality fresh and so forth. For Northeast retailers, both high and medium quality fresh salmon are preferred to frozen salmon.

Restaurants: In the Northwest, restaurant buyers prefer high or medium quality fresh salmon to premium quality frozen.

Expensive seafood restaurants preferred fresh salmon regardless of quality. Among expensive non-seafood restaurants, high quality fresh is considered nearly equivalent to high quality frozen. However, medium quality fresh is preferred to medium quality frozen.

Moderately priced seafood restaurants prefer all fresh products over frozen products, with low quality fresh being approximately equal to high quality frozen. For moderate non-seafood restaurants, high quality fresh is preferred to high quality frozen, followed by medium quality fresh.

Product form and size

Retail: The preferred product for retail buyers in the Northwest is head-off or head-on, 6-9 lb, followed by the 4-6 lb, then the over 9 lb size. All the whole salmon products are preferred to fillets or steaks.

In the Northeast, buyers for retail outlets slightly prefer steaks to whole products in contrast to Northwest buyers. The favored whole product is head-off, 4-6 lb. However, there is less distinction made among the product options relative to the Northwest.

Restaurants: Restaurants in the Northwest apparently prefer larger fish over 9 lb, either head-on or head-off. Steaks are approximately equally preferred to small (2-4 lb) whole fish, which the the lowest rated of whole fish other than pan sized.

In the Northeast, expensive restaurants give the highest rating to fillets, closely followed by larger whole head-on salmon. The results are largely insignificant for moderate restaurants. However, it appears that fillets or steaks are probably slightly preferred.

Color

For Northwest retail and restaurant buyers, "the redder the flesh, the more preferred" apparently holds. For retailers in the Northeast, the pink-red or deep-red are valued equally above light red. Among the restaurants in the Northeast, the coefficient associated with flesh color was of low significance and contrary to that expected for inexpensive restaurants and expensive non-seafood restaurants. For expensive seafood restaurants, the redder the better appears to hold, although with a very low significance level.

Availability

Retail: Year-round availability is preferred to seasonality by both the Northwest and Northeast retailers. Year-round availability is relatively more important to those in the Northeast.

Restaurants: Restaurants in the Northwest, as well as expensive restaurants in the Northeast, have a slight preference for a year-round product. However, several buyers indicate that seasonality is generally not a problem and actually can be a plus in marketing programs. These restaurants often use menu supplements or daily specials which are readily adjusted for seasonal products. On the other hand, moderate restaurants in the Northeast significantly prefer year-round products. A greater proportion of these restaurants have fixed menu items.

Container/box size

Retail: Buyers for retail outlets in the Northwest preferred 50-lb boxes, while retail buyers in the Northeast preferred 10-lb boxes. This is probably associated with the volume of business in terms of average weekly salmon purchases. In the Northeast, retail purchases typically range from 10-100 lb/wk, while in the Northwest, they can typically be from 100-600 lb or more per week.

Restaurants: Restaurants in the Northwest on average were indifferent between 10-lb or 50-lb boxes. Here again, this most likely depends on the restaurant's weekly volume. In the Northeast, smaller units were significantly preferred in all cases except for expensive non-seafood restaurant buyers who were indifferent.

Price

In all cases, except for expensive, non-seafood restaurants, price had a negative impact on preference. In the Northeast, however, there appears to be resistance much below market price for many buyers. The phrase "you get what you pay for" was used to describe low-priced products, implicitly inferring that something must be wrong with the product if the price is too low. This rationale could explain the positive relationship with price and preference for expensive non-seafood restaurants. Price will be dealt with in much more detail in the section on demand.

Demand for Salmon

In addition to the preference trade-offs evaluated by Anderson (1988), demand estimates were also made. It was assumed that salmon buyers have a two-stage decision process. In the first stage, the buyer decides which salmon product among those available in the market is the most preferred for his/her use as was done in the last section. After the salmon is selected, the second decision is to determine the quantity to purchase based on the price, the degree of preference, the price of other fish and the firm's particular characteristics such as customer flow and expenditure.

Buyers were asked their current buying practices. In addition, they were asked the quantity they would be willing to purchase of at least two hypothetical salmon products. Rating scores of the salmon products considered were determined from the interviewee's responses as previously described.

Firm level weekly salmon demand relationships were estimated for Northeast retail and Northwest expensive and moderate restaurants. In all cases, the coefficient on price was negative as expected and, in most cases, it was highly significant. The product's preference rating (score) also was highly significant and positively related to quantity demanded in all cases but one. Number of customers was also a significant variable and positively related to quantity demanded for market segments where the data were available. The estimated demand relationship for buyers in the Northeast retail segment are derived from a relatively small sample and therefore must be viewed with caution. Price elasticities derived from these equations were found to be -1.65 for retail outlets, -0.90 for expensive seafood restaurants, -1.03 for expensive non-seafood restaurants, -0.20 for moderate seafood restaurants and -0.51 for moderate non-seafood restaurants.

Anderson (1988) also determined that the estimated proportion of fresh/frozen salmon sold through restaurants is about 62%, through supermarkets, 15% and through seafood markets, 23%. The figures also indicate that about 37% of the fresh/frozen salmon is consumed in the Pacific region (Alaska, Washington, Oregon, Idaho, Hawaii and California) and 28% is consumed in the Northeast (New England and Middle Atlantic combined).

Using the firm level demand estimates and information on the number of firms in the U.S., Anderson (1988) made some tentative demand forecasts conditioned on assumptions about real growth in disposable income and improving the characteristics of salmon products to better match buyer preferences.

Forecasts for the year 1995 are uncertain and it is risky to attach much importance in predictions in the distant future. However, the estimates indicate that, if real prices (1987 dollars) are constant, with improved marketing and product attributes, demand may increase 44-63% (1% real growth in disposable income) to 56-76% (2% real growth) by 1995 in the restaurant sector and 27-28% (1% real growth in disposable income) to 38-39% (2% real growth) in the retail sector. If the real price drops 20% levels by 1995, then expected demand for the restaurant sector may increase by 92-108% (39,700-46,500 MT) in the restaurant sector and by 96-113% (24,800-28,900 MT) in the retail sector.

It is critical to realize that most of the expansion potential is from an improved product attribute mix reaching the buyer. This implies that more attention to quality, buyer needs and efficient distribution must be in place to realize the forecast gains. One other important consideration is that most of the potential demand increases are for salmon in the off season. Therefore, supplies of high quality salmon in the off season will gain the greater share of potential market increases. Another important point is that the potential market increases are dependent upon consistently available marketing services and efficiently operating marketing systems. This is probably not the case in today's salmon market. There are inconsistencies in supply over the year which will result in chronic gluts and dearths and create significant fluctuations in price. The presence of salmon year round may alleviate some of these problems as plants are utilized more fully to capacity on a year-round basis, lowering marketing costs and increasing efficiency.

JAPANESE SALMON MARKET

Japanese consumption of salmon amounted to 340,000 MT in 1986, which is about 40% of the world's production of salmon (FAO 1987). For many salmon-producing companies, Japan is one of the most important markets. The importance of the Japanese market seems to become even more obvious as the world production of aquacultured salmon increases rapidly. As more producers seek an outlet for their products, the world salmon market tends to become more competitive. A need for detailed information on the Japanese market is acutely felt in the industry.

SUPPLY OF SALMON IN JAPAN

Japan presently obtains 60% of salmon from domestic production (coastal set-net catch, high-seas catch and aquaculture) and 40% from imports. A close look at trends in imports reveals that changes have occurred in the product forms in which salmon are imported. A shift in key suppliers of salmon to Japan has also occurred.

Table 2 traces Japanese salmon imports by country and by product type between 1980 and 1987. Frozen salmon is the dominant product imported. It represented 97.9% of the total Japanese salmon imports in 1987. The frozen salmon import market has been dominated by the U.S., Canada, USSR, South Korea and North Korea. Although the import data are not separated by wild vs aquacultured salmon, the majority of frozen salmon imported from these countries is considered to be wild salmon. Among these countries, the U.S. is by far the largest supplier of frozen salmon to Japan. In 1987, the U.S. supply led 86.5% of Japanese salmon imports followed by Canada with 8.6%. Over 60% of frozen salmon imported is sockeye (Canadian Embassy, Tokyo 1988).

The breakdown of frozen salmon imports by country or origin is shown in Table 3. The shares of the U.S. and Canada are dominant, yet Norway, Chile, Denmark and Sweden have joined the arena. Frozen salmon imported from these countries are aquacultured salmon. Although it is still minimal, imports of frozen aquacultured salmon have shown a steady increase in recent years. This can potentially affect the frozen salmon market in which the U.S. and Canada are the leading players.

Until recently, aquacultured salmon was primarily imported fresh. Those fresh aquacultured salmon went to the restaurant sector and therefore did not directly compete with wild-caught salmon which are more likely to be sold at retail stores. As imports of frozen aquacultured salmon increased, however, more aquacultured products have entered the retail market outlets. Although stores consider these products as added variety rather than something

Table 2. Japanese imports of salmon by major countries (1980-87).

Countries	1980	1981	1982	1983	1984	1985	1986	1987
				Unit: 1000 kg				
Fresh								
United States	6	38	206	1,272	5	146	115	264
Norway	2	29	33	78	179	281	588	1,096
Korea(ROK)	6	427	5	6	68	69	80	20
Other		1	1	1	1	19	82	291
Total	14	495	245	1,357	253	515	864	1,671
Frozen								
United States	33,019	60,212	93,063	86,669	80,271	102,401	95,894	94,311
Canada	2,641	5,157	10,834	3,837	5,178	9,848	15,087	9,429
U.S.S.R.	1,991	2,546	645	254	1,363	1,505	779	2,998
Korea(DPRK)	1,674	3,002	1,501	1,188	1,661	779	1,103	547
Korea(ROK)	6	359	1,362	1,923	1,982	438	291	554
Taiwan	-	-	-	3,687	2,413	-	-	-
Other	1	65	73	283	110	504	274	1,181
Total	39,331	71,341	107,478	97,848	92,978	115,482	113,428	109,020
Cured								
United States	-	-	-	7	695	1,210	352	208
Canada	-	-	-	121	563	743	676	456
Korea(ROK)	-	-	-			-	22	51
Korea(DPRK)	-	-	-	17	9	37	3	3
Other	-	-	-	-	1	91	1	-
Total	-	-	-	145	1,268	2,081	1,054	717

Note - Import from Taiwan has been banned since June 1984.

Table 3. Imports of frozen salmon by country (1983-87).

Country	1983	1984	1985	1986	1987
			Unit: kg		
R Korea	1,922,536	1,982,374	437,835	290,959	554,467
N Korea	1,188,030	1,660,919	779,336	1,103,285	546,714
China	197,559		345,960		25,011
Norway	56,086	109,628	157,317	227,439	355,669
Sweden	-	-	-	5,303	305,459
Denmark	-	108	-	7,902	405,559
U.K.	19	-	148	-	497
Netherland	-	-	-	-	7,000
USSR	254,490	1,363,017	1,505,434	778,593	2,993,386
Canada	3,837,041	5,177,689	9,847,777	15,086,699	9,428,636
U.S.A.	86,669,438	80,271,219	102,400,793	95,893,773	94,310,551
Chile	33,020	-	3,718	33,544	20,047
Argentina	-	-	-	-	7,230
N.Z.	-	-	-	-	55,156
Iceland	-	-	1,000	201	-
Finland	-	-	1,741	-	-
Trinidad	-	-	984	-	-
Taiwan	3,687,012	2,412,811	-	-	-
Belgium	-	180	-	-	-
Ireland	2,585	-	-	-	-
Total	97,847,816	92,977,945	115,482,043	113,427,698	109,020,382

Note - Imports from Taiwan have been banned since June 1984 (Source: Japan Marine Products Importers Association, Tokyo, Japan).

to replace the traditional product line, imports of wild salmon will inevitably be affected as more aquacultured salmon enter the retail outlet route. In the survey conducted by the authors, Japanese buyers for upscale retail stores pointed out that lower prices and the availability in frozen forms are the major requirements for aquacultured salmon to be sold in greater volume in their stores.

Although still minimal compared to frozen salmon, imports of fresh salmon showed a significant increase in recent years. Some of the highly valued species of salmon such as king and sockeye salmon are imported fresh from the U.S. during the beginning of its harvest season (May and June). This was once the only form of fresh salmon imported to Japan. The increase in aquacultural production around the world has changed the content of Japanese fresh salmon imports greatly.

Norway overtook the position of the U.S. as the primary supplier of fresh salmon in 1984. Since then, Norway has kept that position in the Japanese fresh salmon market. Norway is not the only country which is cutting into the ground of historical salmon suppliers such as the U.S., Canada and South Korea. Thanks to aquacultural production, a number of non-traditional salmon producing countries have joined the arena. Table 4 shows Japanese imports of fresh salmon by country between 1983 and 1987. Norway's share is dominant, yet New Zealand, Sweden, Ireland, Chile and the U.K. have successfully increased their relative shares in the Japanese market. Fresh salmon imports by air are predicted to have increased to 2000 MT in 1988 from 1651 MT in 1987. This trend is expected to continue in the near future.

SALMON CONSUMPTION IN JAPAN

Salmon is the most widely consumed species of fish in Japan. It occupies 8% of the total quantity of seafood purchased for home consumption. Most salmon is consumed salted in Japan. In fact, 80% of salmon consumed at home is salted (Statistics and Information Bureau 1987). Salted salmon is usually sold in portions of fillets weighing about 80-130 g at retail fish stores, supermarkets and department stores. These stores offer products in several different degrees of saltiness. In addition to salted salmon, salmon is sold marinated in rice wine lees, fermented rice and bean paste.

Although the majority of salmon is consumed salted, salmon is also consumed fresh. Consumption of fresh salmon showed an upward trend in recent years. Although this is mainly attributable to increased coastal chum salmon catch, domestic aquaculture production and importation of aquacultured salmon have made fresh salmon more readily available. Contrary to common belief, the practice of eating raw salmon was not introduced to Japan until recently and it has not gained wide acceptance yet.

Smoked salmon products are used more as special gift items. There is a widely practiced gift giving tradition in Japan which takes place twice a year. Individuals as well as business give gifts to their relatives and clients. Food and alcoholic beverages are popular items. Among other things, smoked salmon and a whole salted salmon (Aramaki) are widely used as gifts.

Although salmon is consumed widely at home, salmon is not particularly popular in the restaurant sector. Most species of salmon are not as widely served in restaurants as other species of fish. Some of the possible reasons were revealed through interview of restaurants conducted in Japan in spring 1988. Some of the reasons given are listed as follows:

1) Since salmon is so widely consumed at home, it has lost appeal as a restaurant dish.

2) Salmon lacks in theatrical elements appropriate for restaurant entrees.

3) People associate salmon as being inexpensive and therefore do not see good value in salmon as an entree.

4) Most people consider salmon easy to prepare. People demand restaurant dishes that require the skills of the experienced chef.

Positive aspects which make home consumption of salmon so popular, such as relatively inexpensive price, convenience and wide availability have worked against salmon con-

Table 4. Japanese import of fresh salmon by country (1983-87).

Country	1983	1984	1985	1986	1987
			Unit: kg		
R. Korea	5,737	67,797	68,557	79,858	19,890
Norway	77,540	179,082	280,672	587,733	1,096,482
Canada	136	907	4,082	8,771	25,473
U.S.A.	1,272,389	4,509	146,133	115,411	264,499
Sweden	362	-	-	3,978	23,122
U.K.	194	-	4,491	2,076	16,994
Belgium	361	-	-	-	1,120
France	-	96	6,516	-	-
Ireland	-	-	605	-	17,971
Netherland	-	-	4,367	52,497	-
N.Z.	-	-	-	1,961	190,764
Denmark	-	-	-	11,356	1,945
Chile	-	-	-	-	7,738
Australia	-	-	-	-	1,164
Iceland	-	-	-	-	3,740
Total	1,356,719	252,391	515,423	863,795	1,670,902

Source: Japan Marine Products Importers Association

sumption in the restaurant sector. Atlantic salmon, on the contrary, have found their way into restaurant sectors. In addition to the positive reputation of the fish itself, the restaurants claimed that they can emphasize that the salmon they serve is truly different from what customers commonly eat at home.

JAPANESE PERCEPTION OF SALMON

Self-explicated utility measurement was also used for the analysis of the Japanese buyer perception of salmon. The data are based on the 15 completed surveys of Japanese traders in Tokyo conducted by the authors in spring 1988. The results will be compared to the previous study by Seafrea and Anderson (1988). Japanese buyers were first asked to rate the importance of various attributes of a product with the scale of one to a hundred. Relevant attributes chosen for this study were species, region of origin, method of catch, types of product (fresh/frozen), quality, appearance, color of flesh, fat content, price, supply availability, size and product form. After buyers rated the overall attributes, they were asked to rate individual attributes such as sockeye, coho, chinook, chum, Atlantic and pink with the scale of one to ten, comparable to the methods used in the previous studies of the U.S. market.

Overall attributes importance

The results of the overall ratings of the attributes are presented in Fig. 5. Japanese traders in Tokyo and Seattle both ranked quality, price and species high. Japanese traders seem to place more importance on species of salmon than their U.S. counterparts.

Individual attributes importance

Species

Japanese traders in Seattle clearly prefer sockeye salmon. Although Japanese traders in Tokyo show a strong preference toward sockeye, they rated king and Atlantic salmon significantly higher than their counterparts in Seattle (Fig. 6).

Region of origin

Japanese traders in both Tokyo and Seattle prefer Canadian salmon (Fig. 7). They showed some discrepancy in the ratings for Alaskan salmon. While traders in Seattle rate

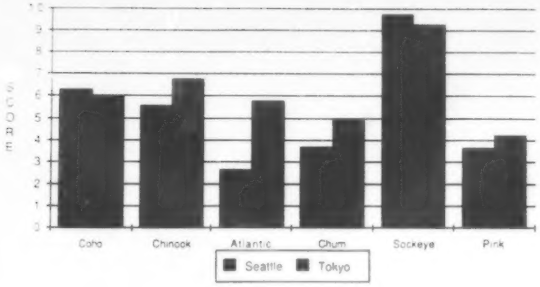

Fig. 6. Preference ratings for salmon species (Japanese traders).

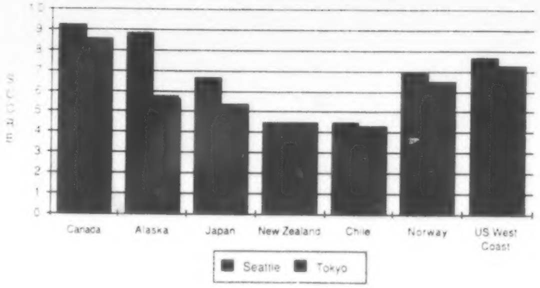

Fig. 7. Preference ratings for region of origin (Japanese traders).

Alaskan products highly, traders in Tokyo rate Alaskan salmon a little better than neutral. Japanese traders in Tokyo place higher ratings on Norway than Alaska. Some of the discrepancy in the ratings among Japanese traders may have come from the locational bias. Since traders in Seattle and Vancouver mainly purchase salmon from Canada, Alaska and the U.S. West Coast, their preference seems to lean toward these regional origins.

Method of catch

Troll caught salmon is perceived as the best method of catch by Japanese traders in both locations. Farmed salmon were rated higher by traders in Tokyo.

Fresh/frozen and quality

High quality frozen is strongly preferred by Japanese traders in both locations, while fresh is definitely preferred over frozen by the U.S. counterparts. Part of the reason is a distance to the market place. While frozen salmon is imported through surface transportation, fresh salmon must be air flown to Japan. Cost of transportation is a definite factor in explaining the preference towards frozen salmon by traders. Although Japanese imports of fresh salmon by air have increased recently, interviews with Japanese traders reveal that they are not yet set up for handling a large quantity of fresh salmon imports. Traders in Tokyo also showed strong preference toward bright silver skin and medium-high fat content.

Product form and size

The favored product form of salmon by Japanese traders in both locations is head-off, gutted, 4-6 lb. Fillet, steaks and pan-size salmon are rated poorly. Traders in Tokyo also showed a strong preference toward 6-9 lb size salmon. Although the majority of frozen salmon imported by Japan is head-off, about 10% of the frozen salmon is imported head-on. These salmon are imported specifically to be processed into whole salted salmon for gift items.

Color

Redder fish is apparently preferred by Japanese traders. This partially explains Japanese apparent preference for sockeye salmon.

Summary of Japanese buyer preferences

Combining individual highest ranking attributes, the most preferred hypothetical product for Japanese traders would be sockeye salmon from Canada, troll caught, frozen, high quality, head-off, 4-6 lb, with deep red flesh color. Japanese are indifferent about seasonal availability.

LIMITATIONS

Limitations of the U.S. and Japanese market studies must also be clearly understood.

1) This study is based on the current tastes and preferences of buyers which can change over time and as a result of promotional efforts.

2) General economic conditions are not stable which erodes the value of distant forecasts.

3) The estimates presented here are based on a relatively small sample and additional work should be done to substantiate or refute these projections.

4) The sample taken in the Pacific Northwest and Northeast may not be representative of conditions currently prevalent in other regions. Therefore, it is expected that the forecast for current demand may be somewhat high. If the current estimate of demand is somewhat overstated, the forecasted increase in demand relative to actual consumption rates is probably somewhat understated.

CONCLUSION

Although some of the results presented in this paper will be refined and further developed as new information is assimilated, there is a substantial amount of information which can help guide salmon aquaculturists in marketing. The evidence indicates that both the U.S. and Japanese markets for salmon are expanding. However, in the U.S., increasing supplies will probably often exceed demand at current price levels. Without improved marketing of salmon to meet the preference of buyers, one can expect some downward price pressure in the next several years. On the other hand, the evidence indicates that the attributes associated with aquacultured salmon are generally preferred and can be modified to meet the needs of current buyers, as well as new buyers of salmon. This will result in substantial possibilities to expand the market beyond current levels.

In Japan, there is an increasing trend toward consumption of fresh salmon. Characteristics of salmon which can be managed, such as size, flesh color, fat content and external appearance can be used to improve the perception of farmed salmon in Japan. Apparently Japanese buyer interest in the exotic products may give suppliers from Norway and elsewhere an additional opportunity in the restaurant segment. High quality frozen salmon from aquaculture may also begin to make significant inroads into the traditional supplies of ocean-caught salmon from the U.S. and Canada.

REFERENCES

Anderson, J. L. 1988. Analysis of the U.S. market for fresh and frozen salmon. Dept. Resource Economics Staff Paper 88-07, College of Resource Development, Agriculture Experiment Station Contrib. No. 2446, p. 84.

Anderson, J. L., and P. Brooks. 1986. Conjoint analysis of the New England salmon market. Prepared for Fish. Oceans Can., Vancouver, B.C. p. 107.

Egan, D., and P. Leitz. 1988. Perspectives on worldwide salmon supplies to the year 2000, p. 123-127. In Aquaculture International Congress Proceedings. Aquaculture International, Vancouver, B.C., Sept. 6-7.

Green, P., and Y. Wind. 1975. New way to measure consumers' judgments. Harvard Business Review 53: 107-117.

Lin, Biing-Hwan, and M. Herrmann. 1988. An econometric analysis of Atlantic salmon markets in the United States. Alaska Sea Grant Rep. 88-5, Univ. Alaska, Fairbanks, AK, p. 19.

Lin, Biing-Hwan, et al. 1988. Future supply and price of Norwegian Atlantic salmon, p. 75-77. In Aquaculture International Congress Proceedings. Aquaculture International, Vancouver, B.C., Sept. 6-9.

Seafare Group, and J. L. Anderson. 1988. World markets for salmon: pen-reared salmon impacts. Report prepared for the State of Alaska, Dept. Commerce, Juneau, AK, April 1988.

Japan Management and Coordination Agency, Statistics Bureau. 1987. Annual Report on the Family Income and Expenditure Survey.

Japan Marine Products Importers Association. 1980-87. Japanese Imports of Marine Products (Statistics). Toyko, Japan.

Statistics and Information Bureau, Ministry of Agriculture, Forestry and Fishery. 1987. Gyogyo-Yoshokugyo Seisan Tokei Nempo (Annual Statistics on Domestic Fisheries Production), Tokyo, Japan.

Suisan Keizai Shimbun Sha. 1988. Suisan Keizai Shimbun (Fisheries Economics Newspaper), March-April.